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STRATIGRAPHY AND SEDIMENTOLOGY OF  
RADIOACTIVE DEVONIAN-MISSISSIPPIAN SHALES OF  
THE CENTRAL APPALACHIAN BASIN  
Final Report

by

Linda J. Provo <sup>1/</sup>

Supervised by

<sup>2/</sup>  
Paul Edwin Potter and J. Barry Maynard <sup>3/</sup>

University of Cincinnati

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<sup>1/</sup>  
Ph.D. candidate, University of Cincinnati, expected graduation June  
1976-77.

<sup>2/</sup>  
Professor of Geology, University of Cincinnati.

<sup>3/</sup>  
Assistant Professor of Geology, University of Cincinnati.

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ABSTRACT

In eastern Kentucky and nearby, the Ohio Shale -- a radioactive, black, organic-rich shale of Late Devonian age -- consists of two dominant lithologic types, which occur in a distinctive stratigraphic sequence. These two lithologies are brownish-black, organic-rich shale and greenish-gray, organic-poor shale and mudstone. Five to seven stratigraphic subunits can be recognized easily in both the subsurface and outcrop and are traceable over most of eastern Kentucky and into parts of adjacent states. These seven units are the Cleveland Shale, Three Lick Bed, Upper, Middle, and Lower Huron Shales, Olentangy Shale, and Marcellus (?) Shale.

Black shale within the Ohio Shale in Kentucky typically contains 30 ppm uranium, while lighter-colored, organic-poor shale contains only 15 ppm. Uranium content of samples from five stratigraphic subunits in Kentucky ranges from 6 to 74 ppm; average content is  $27.7 \pm 3.2$  ppm at 90 percent confidence limits. For all samples from Ohio, Kentucky, Tennessee, and Alabama, average uranium content is  $32.9 \pm 3.9$  ppm at 90 percent confidence limits, with the amount of uranium varying from 1 to 106 ppm. The amount of uranium varies with lithology and geographically. The samples richest in uranium are those black shales from Tennessee and Alabama. In Kentucky, the thickest, most uraniferous units are the Cleveland Shale and the Lower Huron Shale, and the entire formation in the state is estimated to contain  $6.28 \times 10^{12}$  tons of uranium.

Black shales of Late Devonian age have a widespread geographic distribution in North America and on three other continents. The depositional settings of these black shales include: (1) shallow, cratonic seas,

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<sup>1/</sup> Ph.D. candidate, University of Cincinnati, expected graduation June 1976-77.

<sup>2/</sup> Professor of Geology, University of Cincinnati, Cincinnati, Ohio.

<sup>3/</sup> Assistant Professor of Geology, University of Cincinnati, Cincinnati, Ohio.

(2) distal facies of turbidites, and (3) basinal facies associated with reefs. The first two of these environments characterize the Ohio Shale and its equivalents in the central Appalachian Basin.

KEY WORDS: Devonian black shale, internal stratigraphy, subsurface mapping, uranium reserves, sedimentology, and worldwide equivalents.

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#### LIST OF PUBLICATIONS •

##### Abstracts

Provo, L. J. Upper Devonian Black Shale -- Worldwide Distribution and What it Means, in Shumaker, R. C., and W. K. Overbey, Jr., eds., Devonian Shale Production and Potential: Proc. 7th Ann. Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 1-4, 1976, MERC/SP-76/2, pp. 1-3.

##### Papers

Provo, L. J., R. C. Kepferle, and P. E. Potter, in press. Three Lick Bed: Useful Stratigraphic Marker in Upper Devonian Shale in Eastern Kentucky and Adjacent Areas of Ohio, West Virginia, and Tennessee: U. S. Energy Research and Development Administration, Morgantown Energy Research Center, Rept. Inv. MERC/RI-77/1, 58 pp.

## INTRODUCTION

The Upper Devonian shale sequence of the central Appalachian Basin, consisting of the Ohio, Olentangy, and Marcellus (?) Shales and their equivalents, is a distinctive and well-known stratigraphic sequence which is easily recognized both in surface exposures and in the subsurface, is an important producer of natural gas, and contains appreciable uranium.

One of the basic tools for exploiting the resources of the Ohio Shale -- or any other economically significant unit -- is its internal stratigraphy. Without a fundamental stratigraphic framework, without a common stratigraphic language, precise location and prediction of its gas- or uranium-bearing zones is not possible. Furthermore, subdivision of the Upper Devonian black shale sequence, whose thickness ranges from less than 20 feet to over 2,500 feet, into stratigraphic units allows a more meaningful basin-wide analysis of its sedimentology. Thus, depositional history of this formation can be explained in terms of lithologic types and their stratigraphic sequence, once it is identified.

Economic, sedimentologic, and geochemical characterization of the Upper Devonian black shale sequence in the central Appalachian Basin (fig. 1) was accomplished by examination of both subsurface and outcrop data. Nearly 900 wells were studied, approximately half of which have wire-line logs; the remainder have driller's logs (fig. 1). Core from one well and cuttings from 25 wells in Kentucky and three in West Virginia were examined and described (fig. 1). Finally, 10 outcrops of the Ohio Shale and its equivalents in Ohio, Kentucky, and Tennessee (fig. 2) were measured, and descriptions are included as Appendix 1. The amount of uranium in each stratigraphic unit was estimated from analyses of uranium oxide in 101 samples collected from Ohio, Kentucky, Tennessee, and Alabama. Forty of these samples were selected for determination of carbon isotope ratios, extractable organic matter, and total organic carbon. These additional chemical analyses have not been completed yet, but will be included in a supplement to this report.

Previous investigations of the Upper Devonian black shale sequence of the Appalachian Basin have provided a detailed stratigraphy only for the Chattanooga Shale in Tennessee (Conant and Swanson, 1961), which can be subdivided into two members, the Dowelltown and the Gassaway, which are equivalent to the Ohio Shale (Conant and Swanson, 1961, pp. 12-13). In Ohio, three members are recognized (Hoover, 1960): the Huron, Chagrin, and Cleveland. To date, however, no attempts to subdivide the Ohio Shale in eastern Kentucky have been made, and the relationship of the Ohio Shale to equivalent strata in West Virginia and Pennsylvania has not been determined.

The best and most complete discussion of uranium in the Upper Devonian shale sequence is that of Conant and Swanson (1961), who recognize variations in uranium content with stratigraphic position, the upper half of the upper member (Gassaway) being richest in uranium. Brown (1956) and Swanson (1960b) also found that uranium was concentrated in the same stratigraphic units. Breger and Brown (1963, fig. 2) show that the uranium

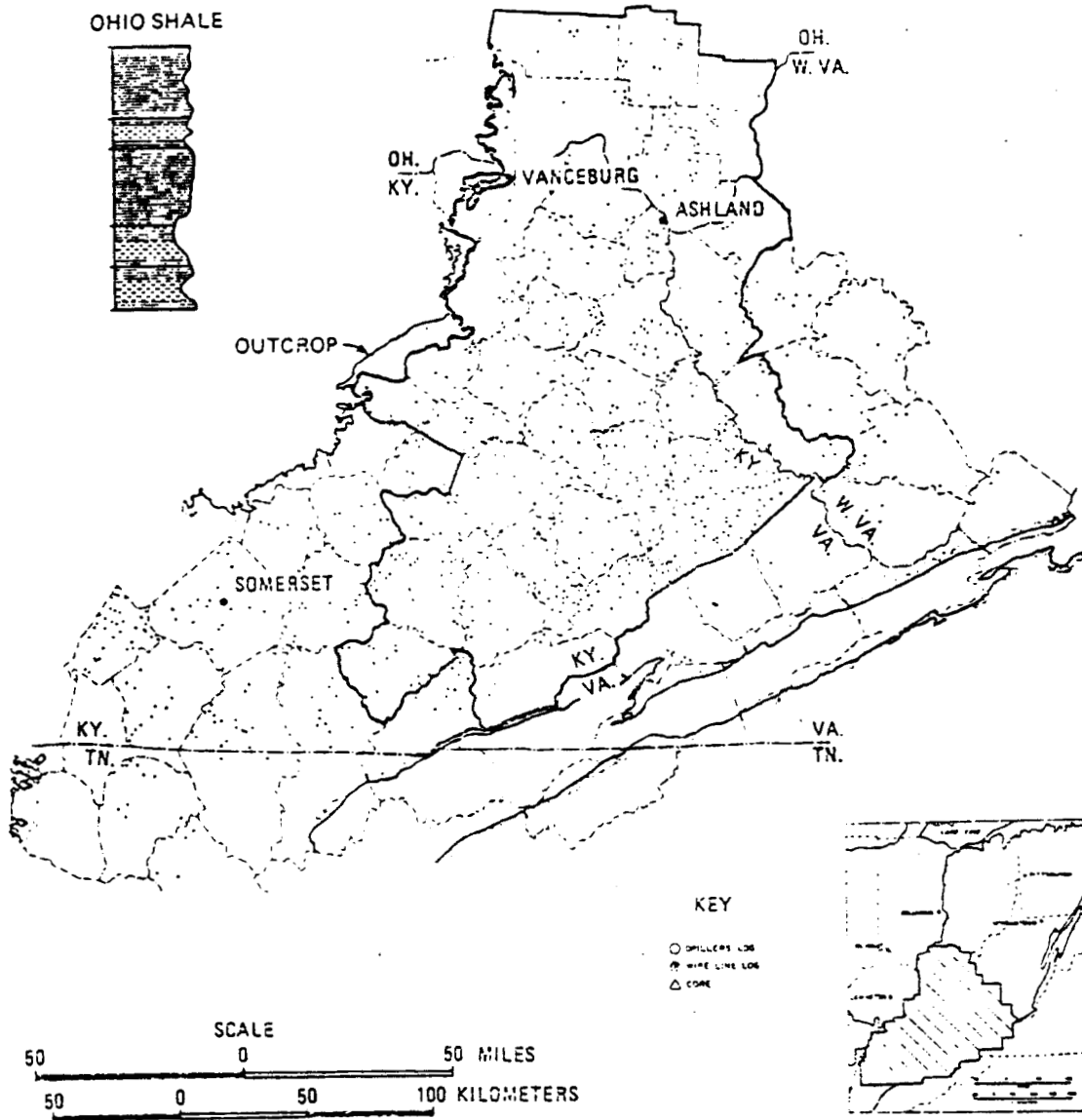
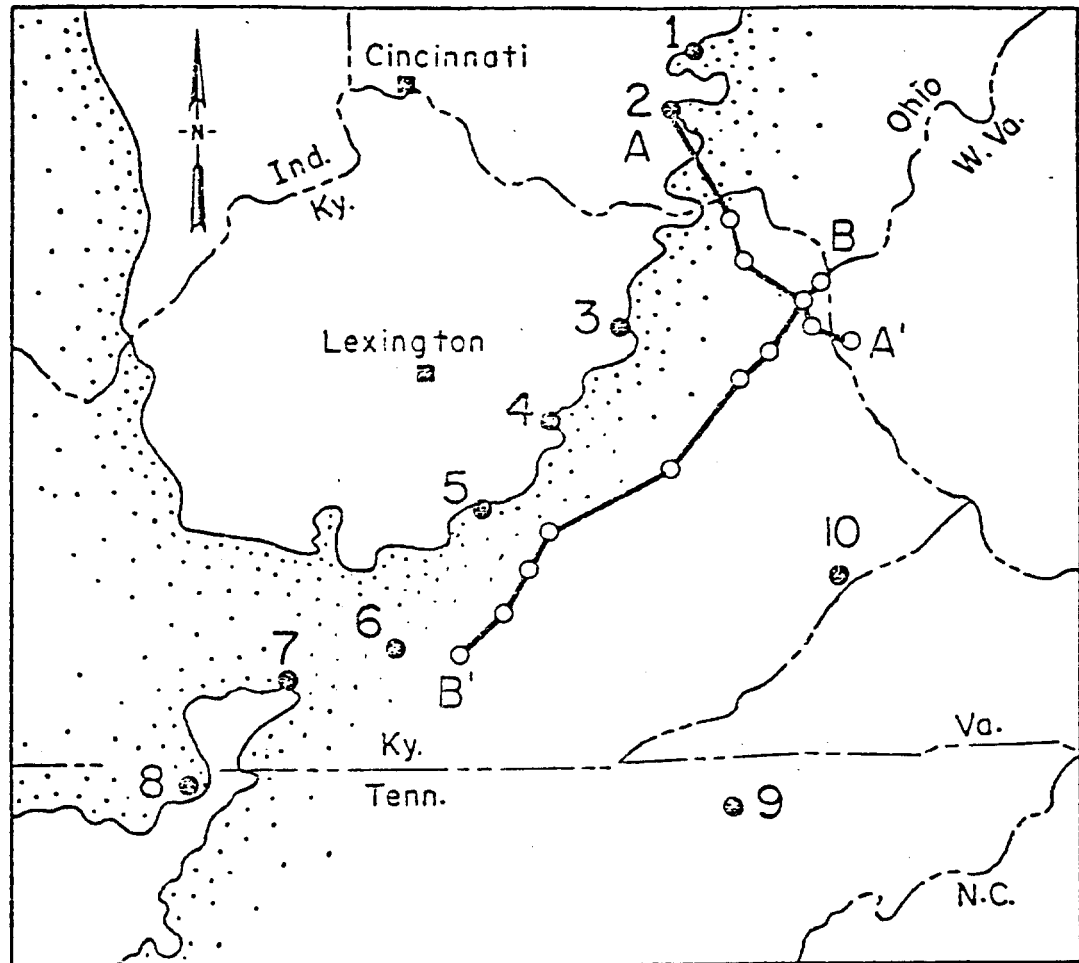


FIGURE 1. --Well control map, showing counties where five to seven subunits of Devonian shale sequence are recognizable.



● Measured Outcrop      ○ Well

FIGURE 2. --Location map of ten outcrop sections and lines of section for cross sections of figure 13.

content of the Chattanooga Shale is greatest in southeastern Tennessee and decreases northwestward across that State. The relationship of uranium to stratigraphy was not mentioned by these authors, but they did show that the amount of uranium is directly proportional to total organic matter (Breger and Brown, 1963, fig. 3).

To summarize, most of what is known about uranium and stratigraphy of the Upper Devonian shale sequence in the central and southern Appalachian Basin concerns the section in Tennessee. Several questions still remain to be answered about the Devonian black shales. What is the internal stratigraphy of the Ohio Shale, Kentucky's equivalent of the Chattanooga Shale? How does Kentucky stratigraphy compare to that of Tennessee or of Ohio? Are surface stratigraphic units traceable into the subsurface? How does uranium content vary with stratigraphy of the Ohio Shale? What are the reasons for such variation, if any? And, finally, what basin-wide trends in uranium content can be identified?

#### CONCLUSIONS

Measured sections and subsurface mapping of the Ohio Shale and its equivalents in the central Appalachian Basin have provided the following stratigraphic conclusions.

1. In northeastern Kentucky and adjacent areas, the Ohio Shale consists of five to seven easily recognized, mappable units in both subsurface and outcrop.
2. In south-central Kentucky, where the shale sequence is thin, these units cannot be separated.
3. From top to bottom, these seven units are the Cleveland Shale, Three Lick Bed, Upper, Middle and Lower Huron Shales, Olentangy Shale, and Marcellus (?) Shale. These stratigraphic names will be formally assigned in a forthcoming publication.

Chemical and petrographic study of samples from these stratigraphic subunits indicate that:

1. The Ohio Shale consists of two dominant lithologic types: dark, organic-rich shale and greenish-gray, organic-poor shale or mudstone.
2. Minor lithologies include limestone with cone-in-cone structure, siltstone, discontinuous beds of pyrite, and phosphatic nodules. Of these, limestone and phosphatic nodules are found consistently in the upper one-third of the Ohio Shale, suggesting that they are stratigraphically significant.
3. Banding in these shales, caused by differences in lithologic constituents, may be related to depositional events within the Appalachian Basin.

4. The amount of uranium in Upper Devonian shales is greatest in Tennessee and Alabama and is controlled by the amount of organic matter and by position within the depositional basin, the latter reflecting specific depositional conditions which led to uranium enrichment.

Economic conclusions include:

1. The amount of uranium in all samples of the Ohio Shale and equivalents ranges from 1 to 106 ppm. The average amount of uranium per unit in the Ohio Shale in Kentucky is  $27.7 \pm 3.2$  ppm at 90 percent confidence limits.
2. For the Cleveland Shale, Three Lick Bed, and total Huron Shale in Kentucky, the arithmetic average amount of uranium per unit with 90 percent confidence limits is as follows:

Cleveland Shale:  $28.9 \pm 6.4$  ppm  
Three Lick Bed:  $15.2 \pm 8.0$  ppm  
Upper Huron Shale:  $31.0 \pm 6.1$  ppm  
Middle Huron Shale:  $30.5 \pm 12.2$  ppm  
Lower Huron Shale:  $31.1 \pm 10.1$  ppm

3. In Kentucky, the five most uraniferous units of the Ohio Shale are estimated to contain  $6.28 \times 10^{12}$  tons of uranium and, thus, must be considered a very low-grade but major source of uranium.
4. The Cleveland and Lower Huron Shales, because they are thickest and easily recognized, would be most suitable for future economic exploration.
5. Per unit area, black shale in central and northern Kentucky and southern Ohio contains more tons of uranium than equivalent shale in Tennessee and northern Alabama, which have much higher concentration of uranium than shale from the northern portion of the study area.

Finally, literature study of other Devonian black shales in North America and other continents suggests that:

1. Deposition of Ohio Shale occurred in very shallow epicontinental seas in the western portion of the Appalachian Basin and in deeper, distal fringes of the Catskill delta.
2. Deposition of black, organic-rich mud occurs when there is both a high rate of production of organic matter and a stratified water mass which encourages its preservation.
3. Black shale of Devonian age is found in 26 states of the United States, six provinces and territories of Canada, and on three other continents.

4. Black shales may occur as distal facies of turbidites in deep water, cratonic deposits in shallow water, or basinal facies near growing carbonate reefs.

#### CHARACTERIZATION OF DEVONIAN BLACK SHALES

Upper Devonian black shales of the central Appalachian Basin were studied from their exposure along the western margin of the basin (fig. 3) eastward into the subsurface of West Virginia. Outcrops of the shale are typically about 40 feet thick in south-central Kentucky (Appendix 1, section 7), but in the subsurface, the same interval thickens to over 2,500 feet in West Virginia (fig. 4). To evaluate the uranium potential of this body of rock, it is first necessary to determine its lithologic and stratigraphic character (fig. 5).

##### Lithology

The Ohio Shale and its equivalents in the western portion of the central Appalachian Basin consist of two dominant lithologies: (1) brownish-black to dark gray organic-rich shale; and (2) greenish-gray shale or mudstone which contains significantly less organic matter and may be dolomitic. Other lithologies occur in minor amounts and include limestone as thin cone-in-cone beds and siltstone either as thin laminae or as discrete beds ranging from 0.1 to 2 feet in thickness as described from exposures in the eastern part of the study area (Appendix 1, sections 9 and 10). Phosphatic nodules, ovoid to amoebiform in shape, occur in the upper few feet of the Ohio Shale and its equivalents (Appendix 1, sections 3 through 8). Spherules, nodules, and irregular aggregates of pyrite are common throughout the entire formation and are locally concentrated along bedding planes.

Fossils commonly observed in outcrop and core include conodonts, linguloid and orbiculoid brachiopods, fish bone and scales. These fossils may be concentrated locally along bedding planes or may occur singly. Coalified wood fragments of Callixylon, amber-colored, spore-like Tasmanites, and the fossil alga Foerstia are also found in the Ohio Shale.

X-ray analyses and thin-section study of samples selected from the two dominant lithologies -- dark, organic-rich shale and lighter-colored, organic-poor shale or mudstone -- show that the dark shale consists primarily of the clay mineral illite, clay-sized quartz, and organic matter. Organic matter, typically reddish-brown, occurs in three forms: (1) as shreds and flakes parallel to bedding; (2) as flattened cases of the spore-like Tasmanites; and (3) as amorphous masses which lend a deep reddish-brown color to fine particles of clay and quartz. Shales which are particularly rich in organic matter contain up to 25 percent, as estimated from examination of thin-sections.

Other constituents observed in thin-section are medium- to coarse-silt-sized, angular and elongate quartz; pyrite blebs, spheres, cubes, and some framboidal masses; and dolomite as irregularly shaped grains and rhombs typically 0.005 to 0.06 mm in size. Generally, these constituents

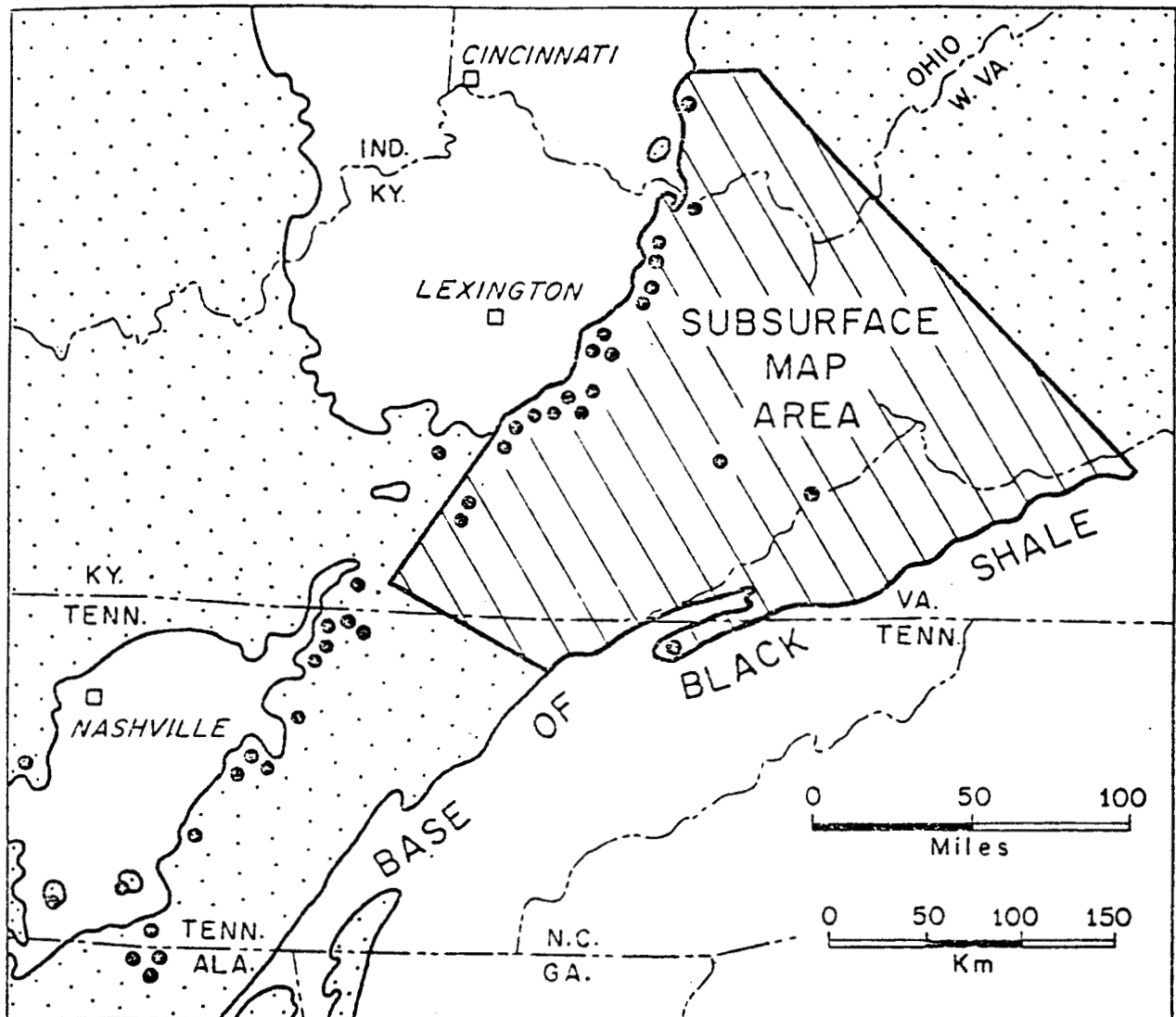


FIGURE 3. --Location map of samples analyzed for uranium oxide and area of subsurface study. Area underlain by Devonian black shale is lightly stippled.

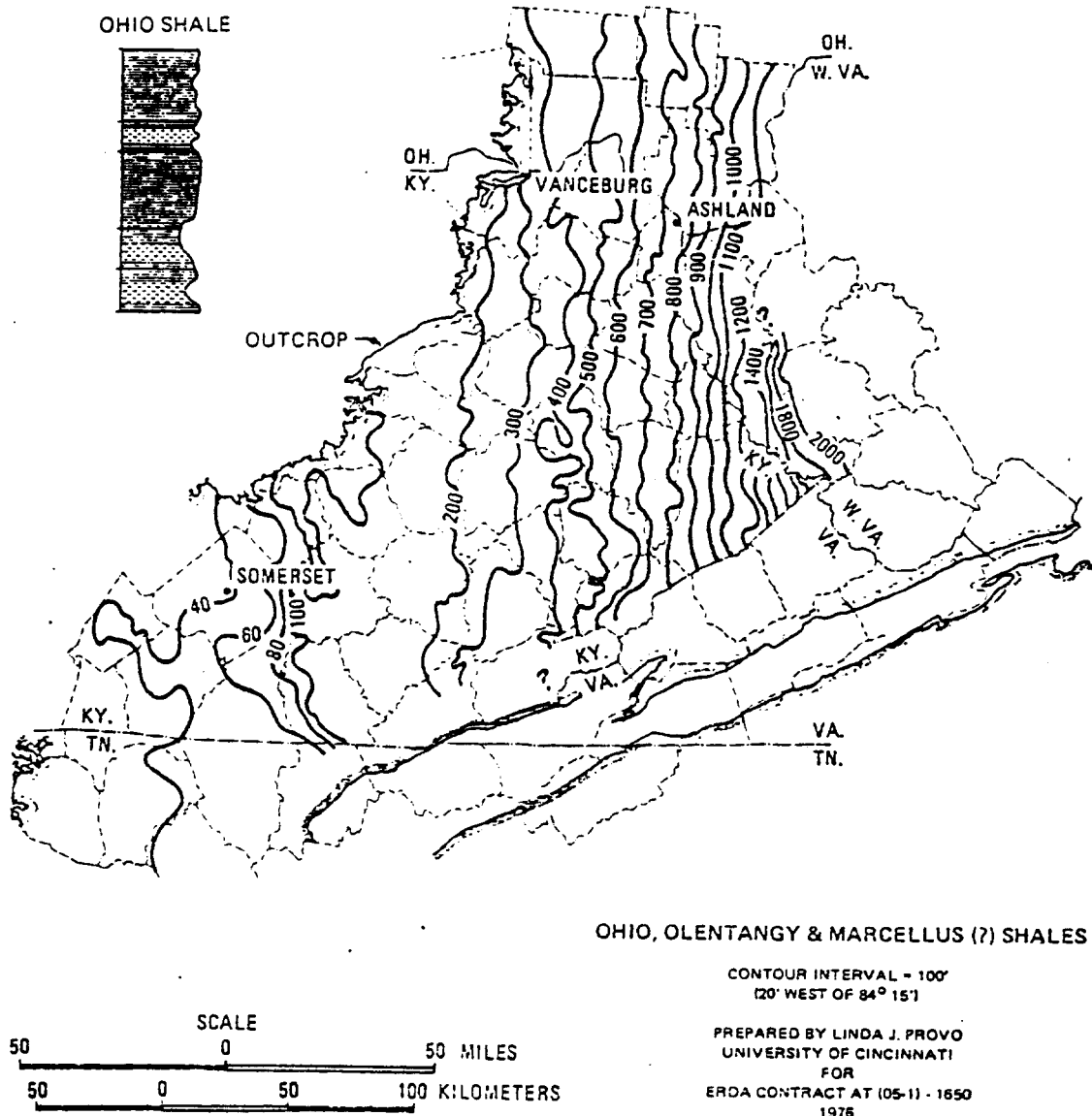


FIGURE 4. --Total isopach map for the Devonian shale sequence (Ohio, Olentangy, and Marcellus (?) Shales). Note rapid thickening in easternmost Kentucky and western West Virginia.

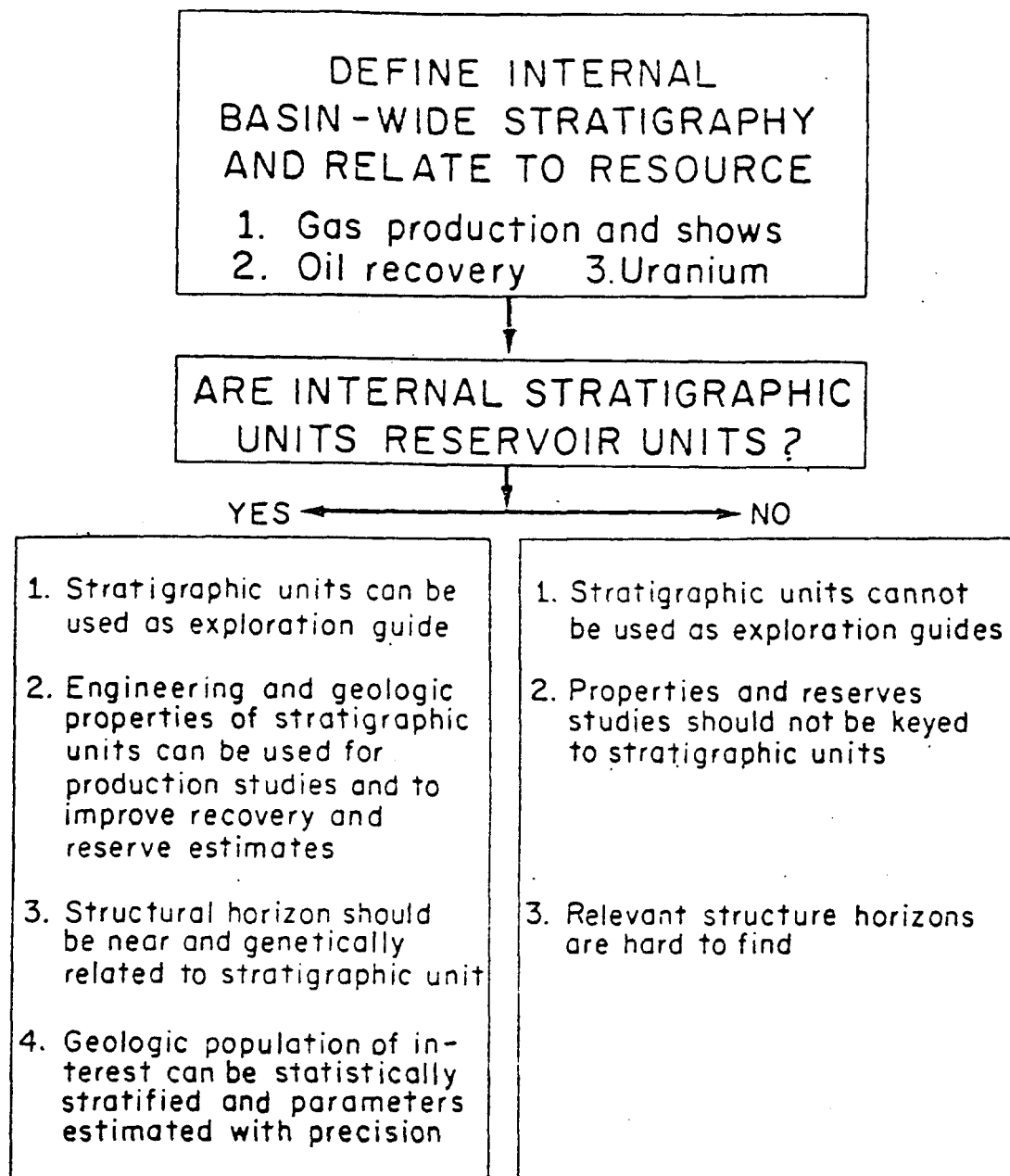


FIGURE 5. --Role of internal stratigraphy in resource appraisal of Upper Devonian shale sequence. Careful definition of basin-wide, internal stratigraphic units is the first key step in evaluation of resources. Once the internal stratigraphic framework is identified, occurrence of gas or other resources can be related to it, and exploration can proceed most systematically and efficiently.

make up no more than 10 to 15 percent of organic-rich shale. Chert, plagioclase feldspar, and muscovite as single grains were occasionally observed.

In contrast, organic-poor shale and mudstone contain notably less organic matter with a corresponding increase in clay minerals and minor constituents such as quartz, pyrite, and especially dolomite. Examples of organic-rich and organic-poor shale, siltstone, and limestone with cone-in-cone structure are shown in the photomicrographs of figure 6, all of which are magnified 40 times.

Bedding in both of these lithologies is emphasized in several ways. Shreds of organic matter and flattened spores show a preferred orientation, parallel to bedding. Long axes of elongate quartz grains are also aligned parallel to bedding. Variation in the amounts of certain constituents also defines bedding. For example, concentration of organic matter is not uniform, but increases and decreases from one bedding plane to the next. This is generally recognizable by changes in color.

Laminae of silt-sized particles consisting primarily of quartz accentuate bedding. Thickness of such laminae is typically 0.50 mm and less. Pyrite blebs and spherules, when present, may be concentrated along bedding planes, and fine-grained (0.06 mm and less) dolomite may occur in laminae one or two grains thick.

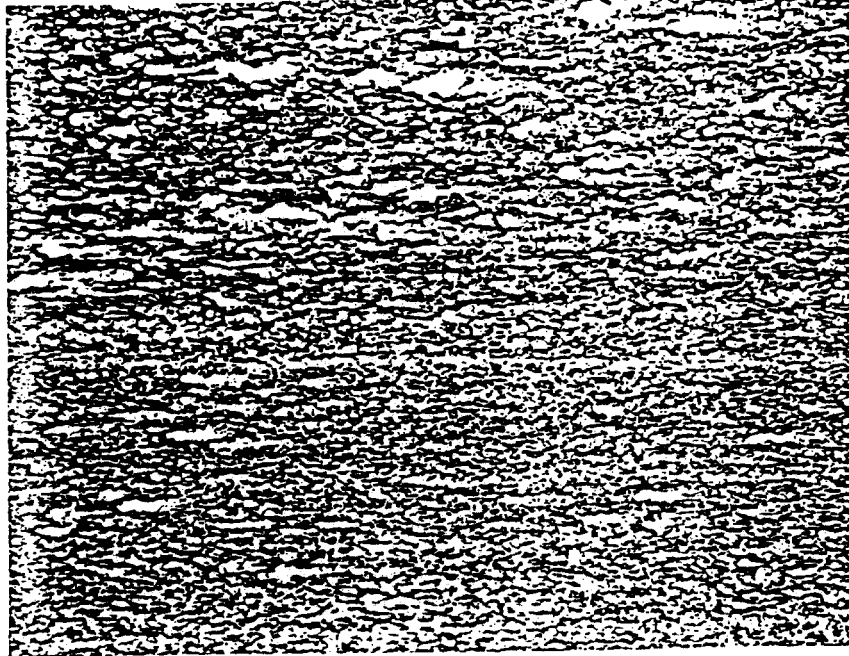
In the organic-poor shales, inorganic constituents define bedding. Such shales, however, are typically poorly laminated because of lack of platy particles (except clay minerals) and of contrast in lithologic constituents, both of which emphasize bedding.

In outcrops, cores, and thin-section, the alternation of black, organic-rich shale and greenish-gray, organic-poor shale produces a banding (fig. 6.A.2). It is possible that such banding in these shales could be interpreted as a response to depositional events. Hesse (1975) suggested that lithologic characteristics such as color, bioturbation, grain size, and grading can be used to differentiate turbiditic mudstones from pelagic mudstones.

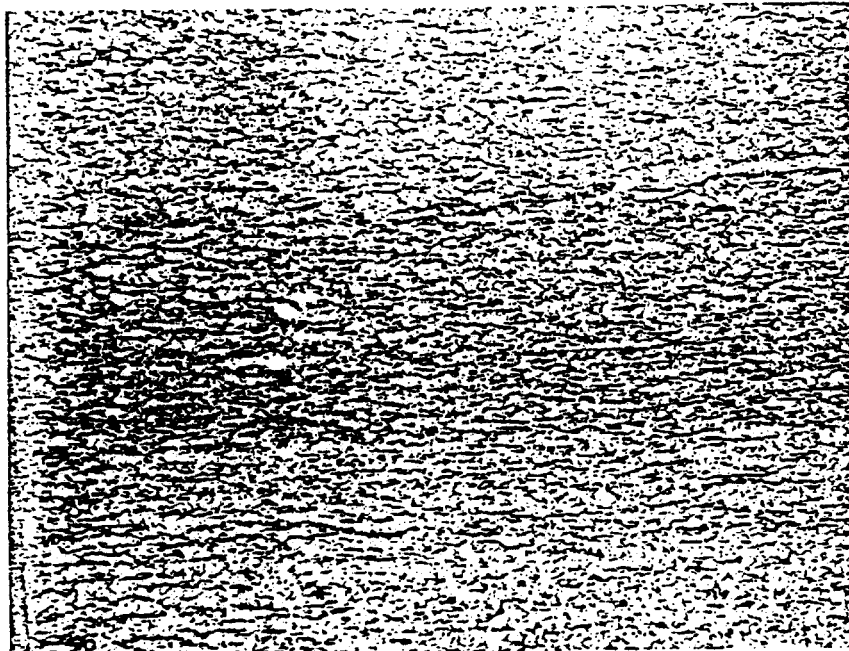
Similarly, banding, which is produced by differences in lithologic constituents, may be related to the origin of these shales. Organic-poor shales probably are deposited when there is an increase in clastic materials introduced into the basin, perhaps by turbidity currents some distance from where these shales are being deposited. Such an increase would have a twofold effect: (1) dilute the organic matter; and (2) destroy organic matter by improving circulation.

Thus, banding in shales is likely a response to depositional events in other parts of the basin. Careful petrographic study of other shale sequences is needed to document further this phenomenon.

The two lithologic types, therefore, which characterize the Ohio Shale in the central Appalachian Basin are easily distinguished in the

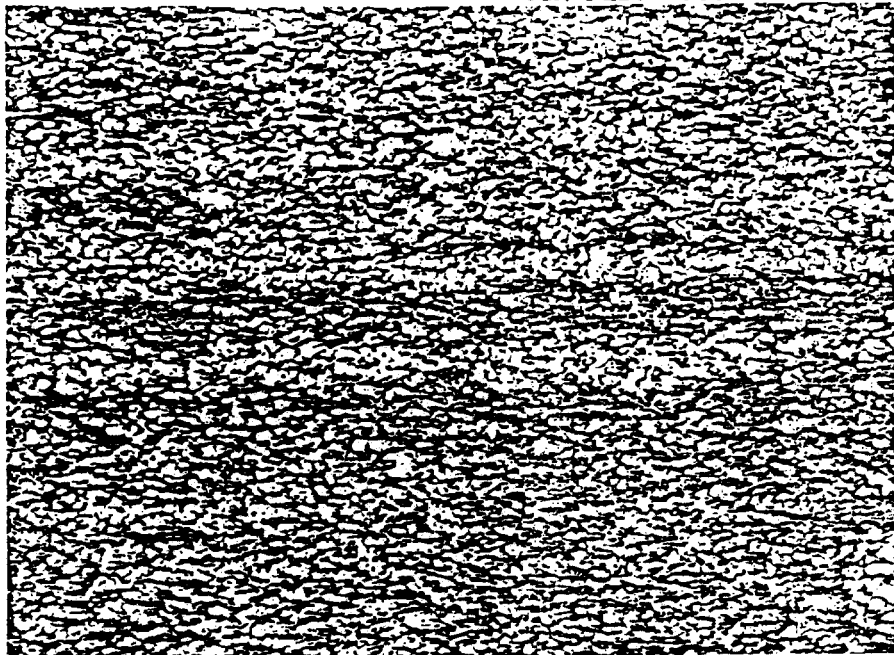


1. Dark, organic-rich shale. Sample no. 17331. Note shreds of organic matter (white) which define bedding, and variation in concentration of organic matter, shown by light and dark bands. 40x.

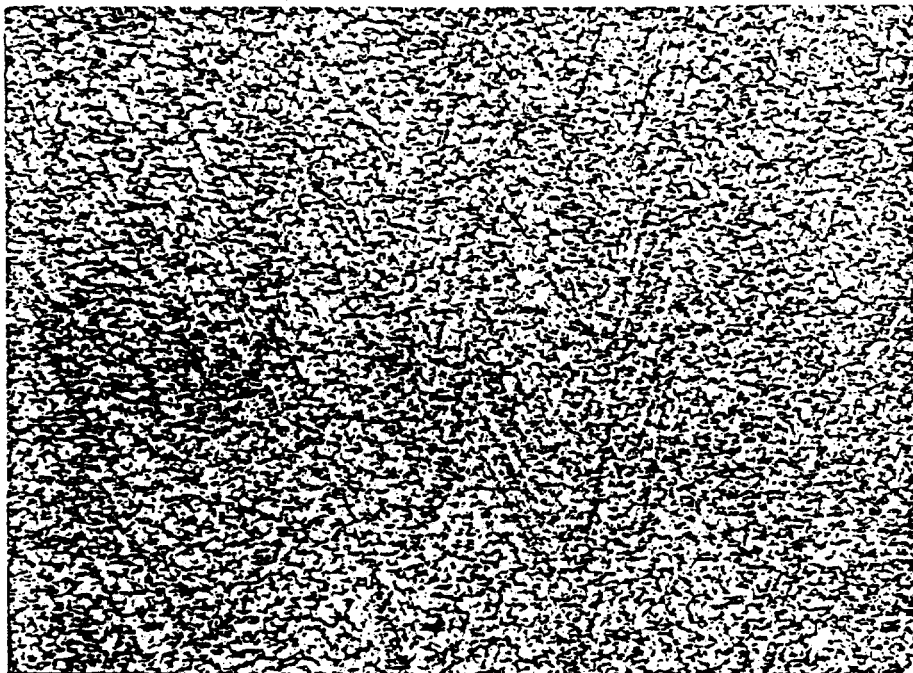


2. Light, organic-poor shale enclosing a band of dark, organic-rich shale. Sample no. 17334. 40x.

6.A. Photomicrographs of thin-sections of shaly lithologies from the Upper Devonian shale sequence.



1. Argillaceous siltstone with streaks of dark, carbonaceous material. Unit 23 of Mountain Branch section (Appendix 1, section 10). 40x.



2. Limestone with cone-in-cone structure. Unit 17 of Tener Mountain section (Appendix 1, section 2). 40x.

6.B. Photomicrographs of thin-sections of non-shaly lithologies from the Upper Devonian shale sequence.

field by color and are further differentiated in thin-section by composition. The next question to consider is the vertical arrangement of these two lithologies. Is there an orderly, recognizable, and traceable sequence in which these rock types occur?

### Stratigraphy

Over much of the area studied, a definite internal stratigraphy can be recognized within the Ohio Shale. Five to seven units can be discerned in the subsurface on gamma ray logs (fig. 1), except where thickness of the Ohio Shale and its equivalents is less than 75 feet. The same units are also found in outcrops where the thickness of the shale exceeds 75 feet. Because most of the Ohio Shale is not exposed at the surface, it is suggested that a reference subsurface section which clearly shows the stratigraphic subunits in the Ohio Shale be designated. A suitable well for which there are gamma ray and compensated formation density curves and a complete set of well samples is the Inland Gas Company No. 533 Coalton Tract Fee, 1,030 feet from the north line and 1,310 feet from the west line of section 11-V-81, Boyd County, Kentucky (fig. 7).

In this log, seven units within the Devonian shale sequence can be separated on the basis of their gamma ray characteristics. From top to bottom these units are: (1) Cleveland Shale; (2) Three Lick Bed; (3) Upper Huron Shale; (4) Middle Huron Shale; (5) Lower Huron Shale; (6) Olentangy Shale; and (7) Marcellus (?) Shale. The first five units listed are equivalent to the Ohio Shale (see Hoover, 1960; for Ohio stratigraphy) with the Three Lick Bed being a tongue of the Chagrin Shale. These stratigraphic names will be assigned formally to the seven units of the Devonian shale sequence in Kentucky in a forthcoming publication. The gamma ray characteristics of each unit are described in Table 1. Also shown in this table are lithologic interpretations of each unit based on gamma ray curves, sample study, and comparison of measured outcrop sections (fig. 2) and range in thickness for each unit (see also figs. 8 through 12).

In general, if thickness of the Devonian shale sequence is greater than 50 feet, at least the Cleveland, Three Lick Bed, and Huron Shale and, commonly, the Olentangy and Marcellus (?) may be recognized (fig. 1). In thinner sections, there is a loss in resolution of these units both in the subsurface and in outcrop (Appendix 1, sections 6 through 8; fig. 6).

The reasons for this loss in resolution are both mechanical and geological. First, wire-line logs are necessary to identify these units in the subsurface. Where key beds, such as the gray and black shales of the Three Lick Bed, are less than two feet thick, they are too thin to produce a response on the gamma ray curve (see fig. 8, Provo, Kepferle, and Potter, in press). Also, the gamma ray curve of many wire-line logs which penetrate thin sections commonly goes off-scale, eliminating any small responses. On such logs, only the upper and lower contacts of the Devonian shale sequence may be picked with certainty. Finally, because the thinnest sections occur close to the basin's western limit, deposition may have begun later here, causing an overlapping of the lower units. The Cleveland

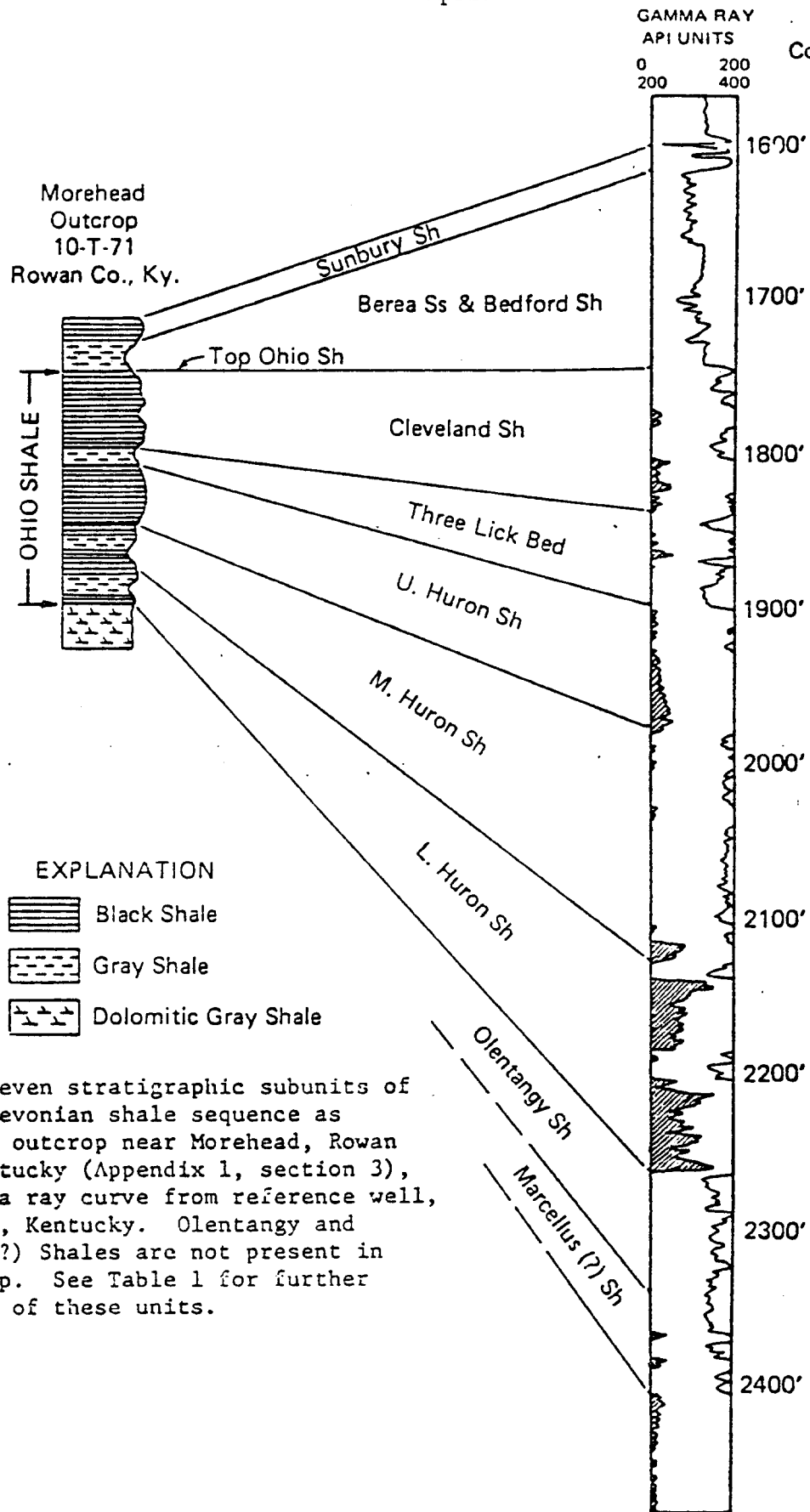


FIGURE 7. --Seven stratigraphic subunits of the Upper Devonian shale sequence as observed in outcrop near Morehead, Rowan County, Kentucky (Appendix 1, section 3), and on gamma ray curve from reference well, Boyd County, Kentucky. Olentangy and Marcellus (?) Shales are not present in this outcrop. See Table 1 for further description of these units.

## OHIO SHALE

## HURON SHALE

UNIT	RANGE IN THICKNESS (FT.)	GAMMA RAY CURVE CHARACTERISTICS	LITHOLOGIC INTERPRETATION
CLEVELAND SHALE	5 - 200	Radioactivity close to or exceeding 200 API units.	Brownish-black, organic rich shale with phosphatic nodules near top.
THREE LICK BED	<1 - 70	Three or four closely spaced negative deviations (less than 200 API units) on gamma ray curve.	Interbedded brownish-black and greenish-gray shales or mudstones; limestone with cone-in-cone may be present.
UPPER HURON SHALE	15 - 115	Moderately radioactive, between 100 and 200 API units.	Massive brownish-black shale.
MIDDLE HURON SHALE	20 - 200	Slightly less radioactive than Upper Huron Shale.	Brownish-black and gray shales, interbedded in lower half; <u>Foerstia</u> found in outcrop and core.
LOWER HURON SHALE (driller's cinnamon or brown shale)	20 - 400	Highly radioactive, usually exceeding 200 API units, with 1 to 4 thin zones of lesser radioactivity.	Brownish-black, organic rich shale with 1 to 4 thin zones of greenish-gray to gray shale.
OLENTANGY SHALE (driller's white slate)	10 - 300	Low radioactivity, typically 100 API units.	Greenish-gray to gray, organic-poor shale and mudstone; may be calcareous.
MARCELLUS (?) SHALE	20 - 250	Thin intervals of high radioactivity (<200 API units) within zones of moderate radioactivity (100-200 API units)	Greenish-gray shale interbedded with brownish-black, organic-rich shale; commonly pyritic.

TABLE 1. -- Unraveling of several sections of the Ohio Shale in central Appalachian Basin, based on 900 wells and 10 outcrop sections, and suggested stratigraphic equivalents

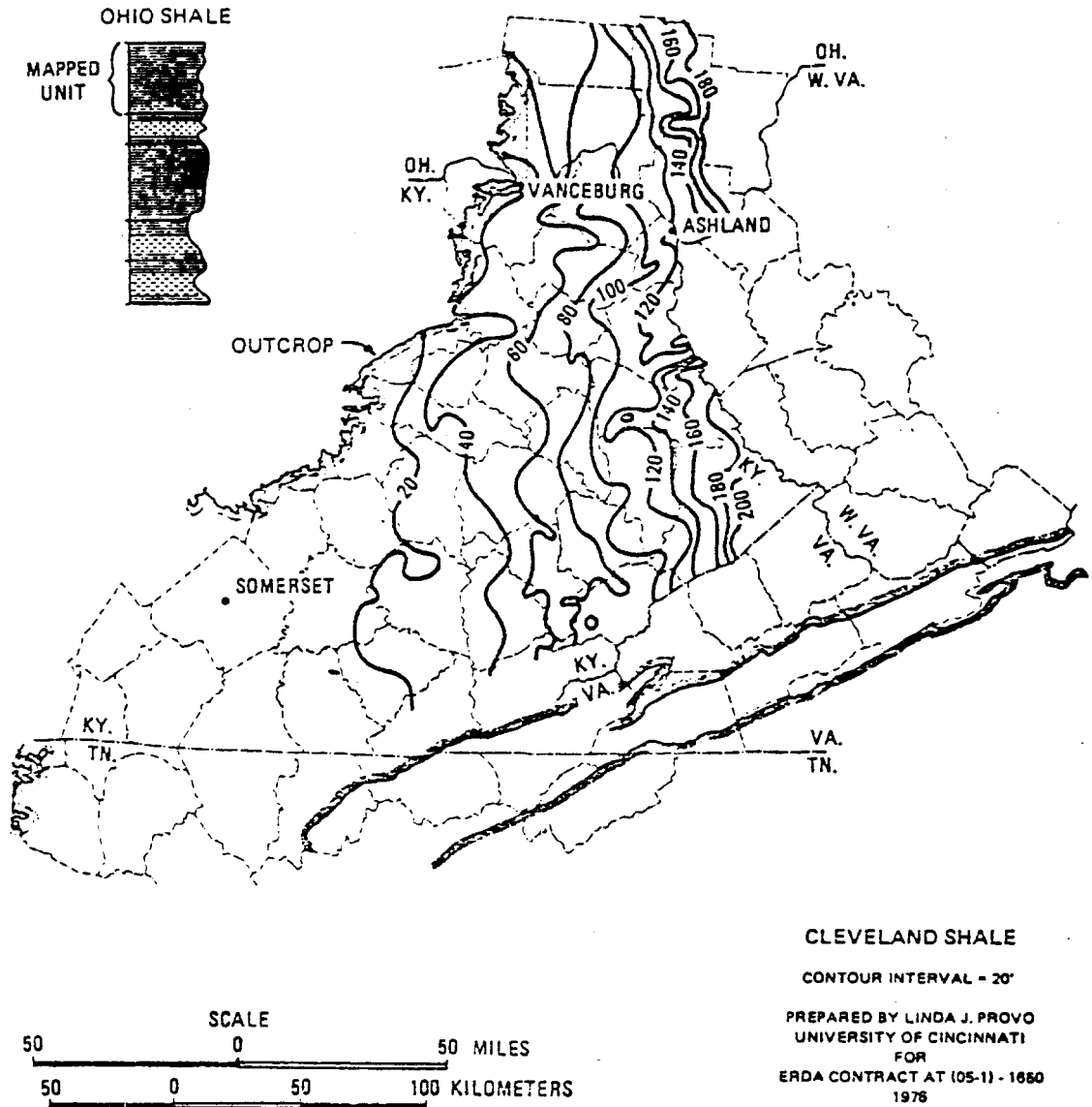


FIGURE 8. --Isopach map of Cleveland Shale showing slight thickening related to structural features in east-central Kentucky.

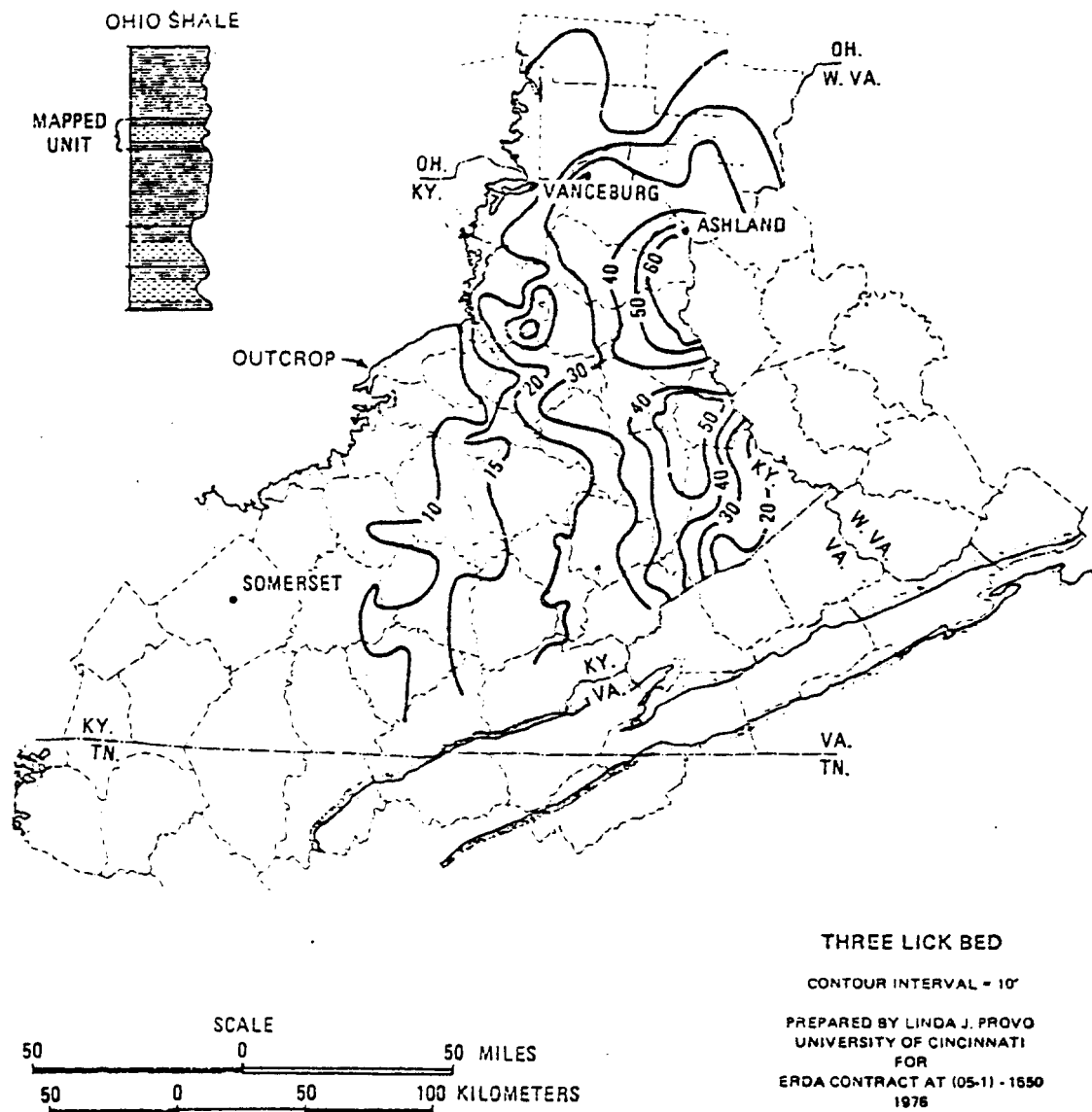


FIGURE 9. --Isopach map of Three Lick Bed (partial equivalent of Chagrin Shale). Note two lobate areas of maximum thickness in eastern Kentucky.

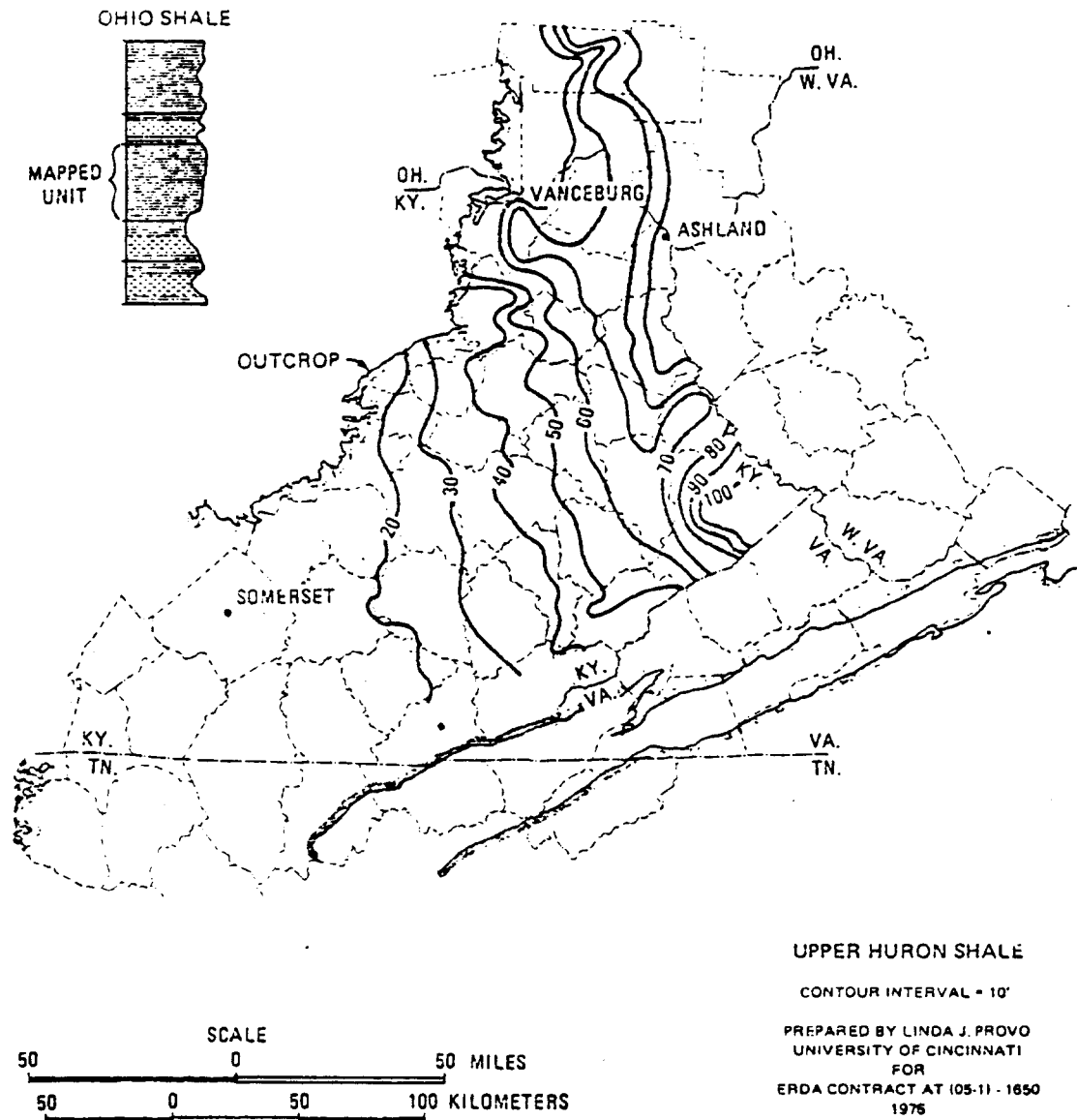


FIGURE 10. --Isopach map of Upper Huron Shale. Part of the Chagrin Shale of Ohio may be included in this unit.

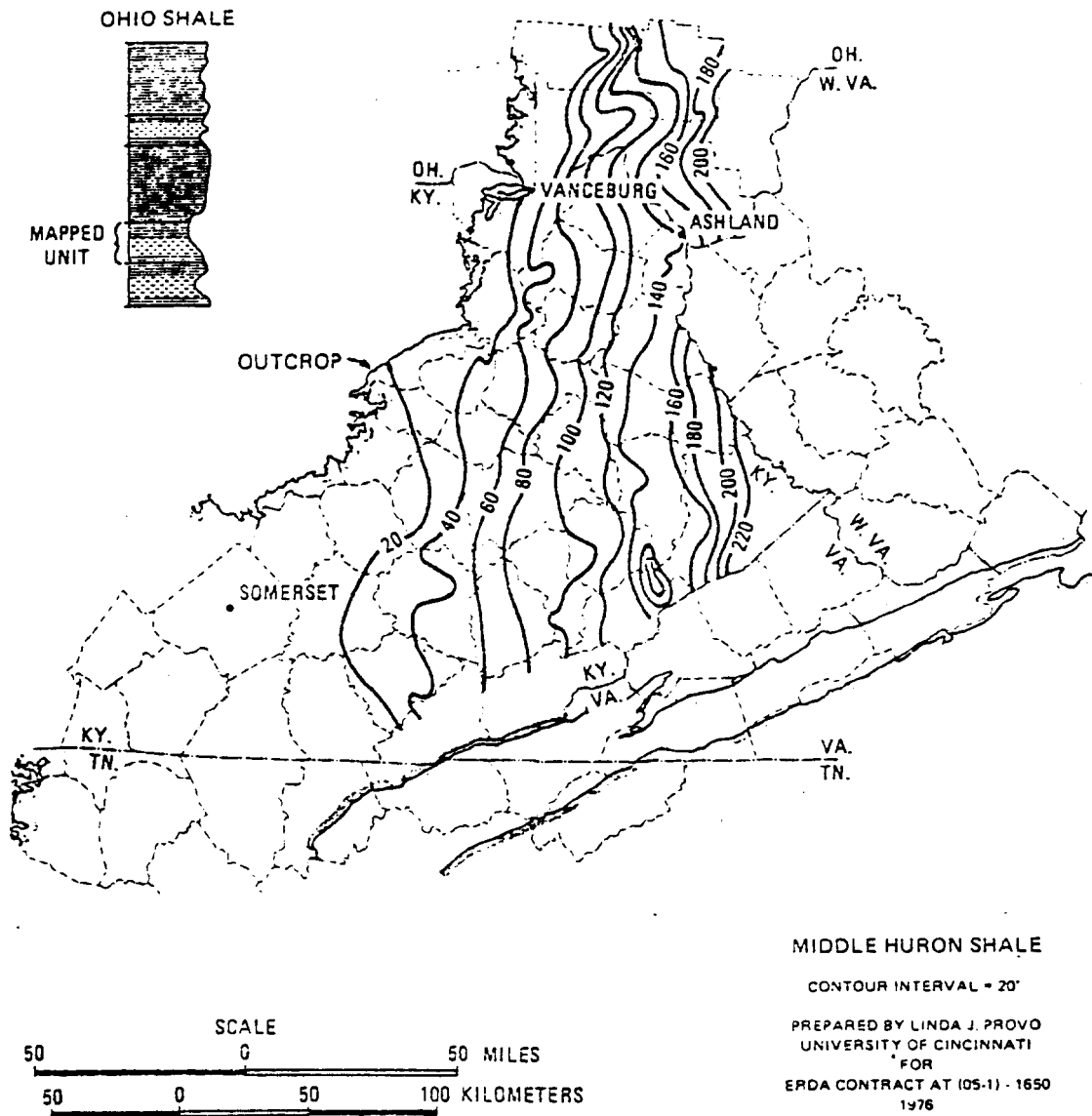


FIGURE 11. --Isopach map of Middle Huron Shale showing locally thick areas in southeastern Kentucky.

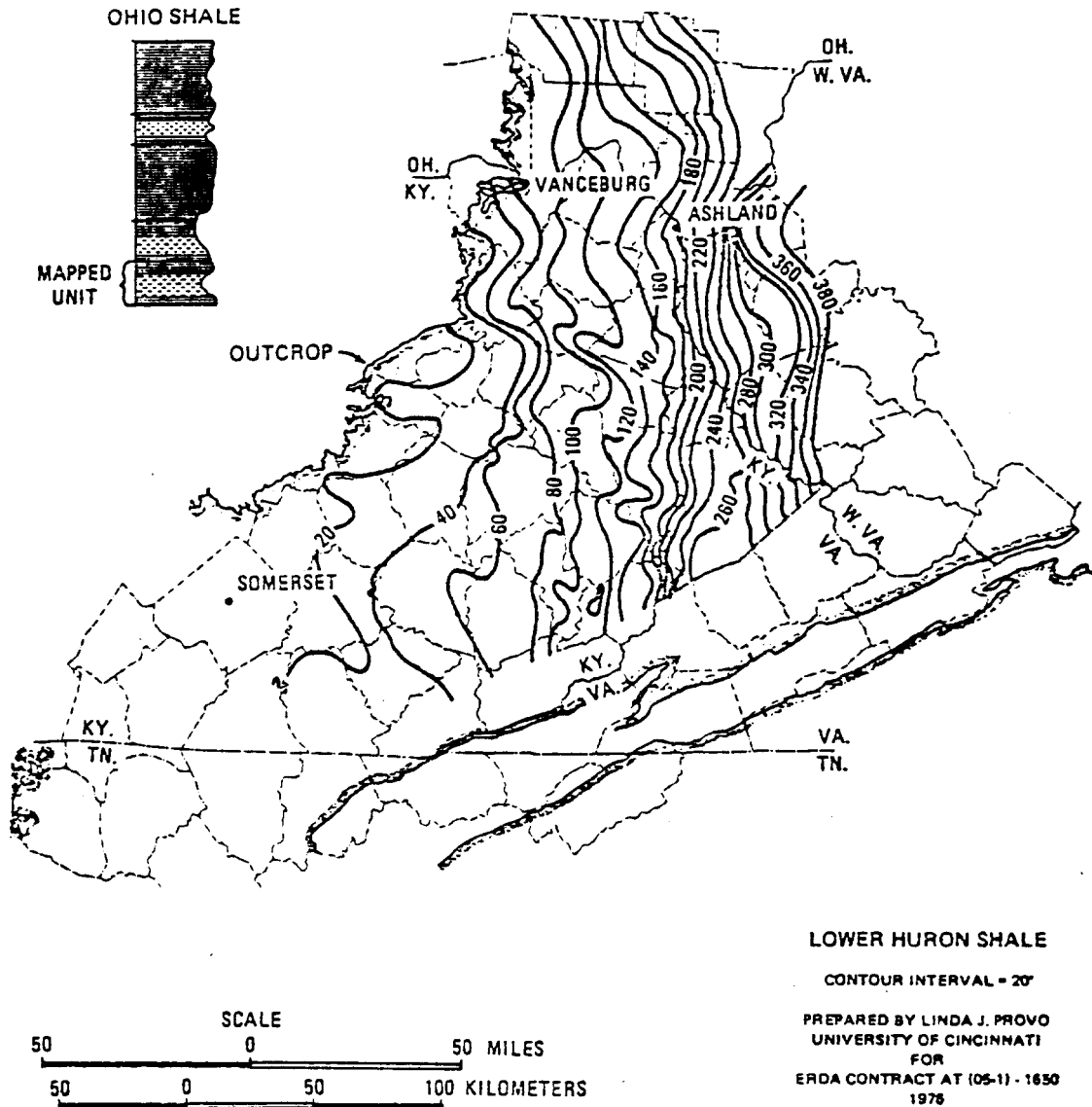


FIGURE 12. --Isopach map of Lower Huron Shale, which is easily traceable into West Virginia. Structural features dating from Precambrian time influenced deposition of this unit in east-central Kentucky.

Shale, with its characteristic phosphate nodules, the Three Lick Bed, and probably the Upper Huron Shale have all been traced in thin outcrop sections as far south as northern Tennessee (Appendix 1, sections 6 through 8), but underlying units probably do not extend this far south.

As the black shale interval thins in the subsurface, the Cleveland, Three Lick Bed, and Lower and Middle Huron first become indistinguishable, while the Lower Huron remains traceable because of its distinctive gamma ray characteristic. The Lower Huron probably is absent in extremely thin subsurface sections as it is in thin outcrop sections.

The Lower Huron Shale persists eastward into West Virginia (fig. 12) as the total section thickens, while the Cleveland Shale, the Three Lick Bed, and the Upper and Middle Huron Shales become inseparable, probably due to a dilution of organic-rich shales by siltstones and organic-poor shales. In two of the measured sections (Appendix 1, sections 9 and 10) in the southeastern part of the study area, siltstone and organic-poor shale account for more of the total section than black, organic-rich shale does. In eastern West Virginia, Pennsylvania, and New York, Devonian rocks equivalent to the black shale sequence include sandstones and siltstones of the Brallier, "Chemung", and Catskill Formations (Oliver and others, 1971), but few dark, organic-rich shales. The Olentangy and Marcellus (?) Shales occur more commonly in the eastern portion of the study area (fig. 13) and are thickest in easternmost Kentucky and in West Virginia.

The regional persistence of these seven units is shown in figure 13, in which these units are traced from southern Ohio southeastward to West Virginia and southward to south-central Kentucky (fig. 2 and Table 2). The loss of the Cleveland, Three Lick Bed, and the Lower and Middle Huron, then the Olentangy and Marcellus (?) Shales and, finally, the Lower Huron occurs as the Devonian shale sequence is traced from Ohio to Kentucky (fig. 13).

#### Regional Correlation

The regional persistence of these units of the Ohio Shale in Kentucky suggests an important question. Are these units correlative with published stratigraphic subunits of the Ohio Shale in Ohio (Hoover, 1960) and the Chattanooga Shale in Tennessee (Conant and Swanson, 1961)? The black shale sequence in Kentucky (fig. 6) is broadly similar to that in both Ohio and Tennessee in that it consists of upper and lower black shales (Cleveland and Lower Huron) enclosing a black shale and interbedded gray and black shales (Three Lick Bed, Upper and Middle Huron).

The Chattanooga Shale can be subdivided into the same number of units as the Ohio Shale, with good lithologic correspondence (fig. 14). Provo, Kepferle, and Potter (in press) correlate the Three Lick Bed with the middle unit of the Gassaway on the basis of outcrop study. Comparison of Ohio and Kentucky stratigraphy (fig. 14) suggests that the Huron Shale in Ohio could be subdivided further into three units, corresponding to the Upper, Middle, and Lower Huron in Kentucky. In addition, if the Three Lick Bed is partially equivalent to the Chagrin, a facies change occurs as

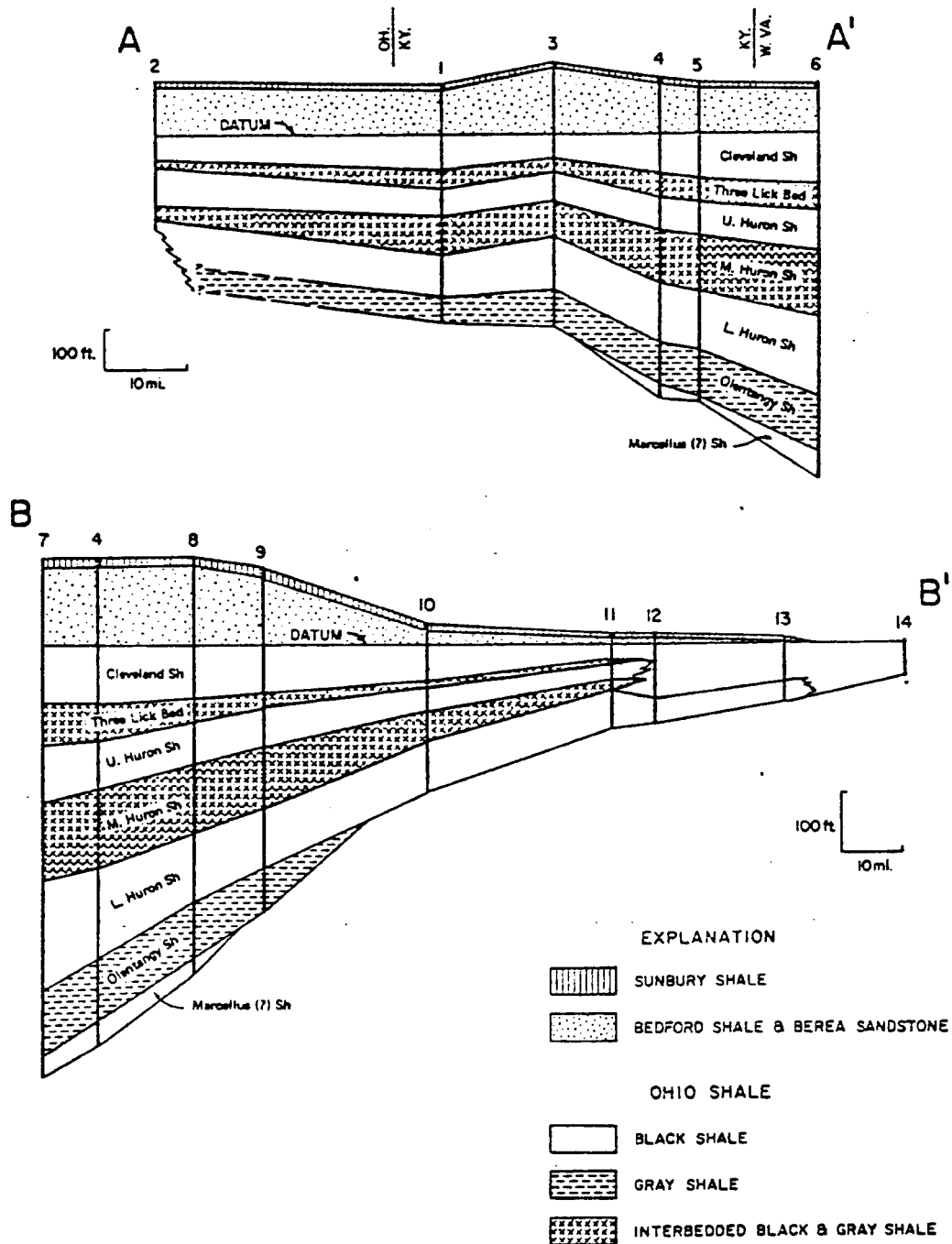


FIGURE 13. --Schematic cross sections showing internal stratigraphy of the Upper Devonian shale sequence in eastern Kentucky and nearby. Datum is top of Ohio Shale; undivided Bedford Shale and Berea Sandstone overlie datum. (See figure 2 for lines of section; numbers refer to well locations in Table 2)

TABLE 2. — Outcrop section and wells used in construction  
of cross sections, figure 13.

Outcrop 2. Tener Mountain, Adams County, Ohio  
(see also Appendix A)

Wells with wire-line logs

- (1)..... Ashland Oil No. 1 Gilliam  
16-Z-78  
Greenup County, Kentucky
- (3)..... United Carbon No. 1 Felty, et al.  
3-W-79  
Greenup County, Kentucky
- (4)..... Inland Gas No. 533 Coalton Tract Fee  
11-V-81  
Boyd County, Kentucky
- (5)..... Inland Gas No. 542 Young  
6-U-82  
Lawrence County, Kentucky
- (6)..... United Fuel Gas No. 9509-T United Fuel Gas Fee  
Deed 9342  
Permit No. 1549  
23-T-84  
Wayne County, West Virginia
- (7)..... Inland Gas No. 539 Daniels  
5-W-83  
Boyd County, Kentucky
- (8)..... Monitor Petroleum No. 2-G Ison-Stephens Unit  
13-T-79  
Elliott County, Kentucky
- (9)..... Monitor Petroleum No. 1 Ison  
3-R-78  
Morgan County, Kentucky
- (10)..... Holly Creek Production No. 2 White  
20-O-73  
Wolfe County, Kentucky
- (11)..... L. O. Hale No. 1 Bowman  
22-L-69  
Owsley County, Kentucky
- (12)..... Planet Petroleum No. 1 Cavins  
1-J-68  
Jackson County, Kentucky
- (13)..... R. D. Acha No. 1 Stewart  
13-B-65  
Laurel County, Kentucky
- (14)..... D. Proctor No. 1 Slavins  
24-H-61  
Pulaski County, Kentucky

<u>TENNESSEE</u>			<u>KENTUCKY</u>			<u>OHIO</u>		
CHATTANOOGA SHALE	Upper Gassaway (black shale)	OHIO SHALE	Cleveland Shale (black shale)	OHIO SHALE	Cleveland Shale (black shale)			
	Middle Gassaway (gray + black shale)		Three Lick Bed (gray + black shale)		Chagrin Shale (mudstone + siltstone)			
	Lower Gassaway (black shale)		Upper Huron Shale (black shale)		Huron Shale (black + gray shale)			
	Upper Dowelltown (gray + black shale)		Middle Huron Shale (gray + black shale)					
	Lower Dowelltown (black shale)		Lower Huron Shale (black shale)					
		OLENTANGY SHALE	OLENTANGY SHALE	Upper (gray shale)				
		MARCELLUS (?) SHALE		Lower (black shale)				

FIGURE 14. --Comparison of stratigraphic nomenclature and lithology of Chattanooga Shale (Tennessee), Ohio Shale (Kentucky), and Ohio Shale (Ohio).

the Chagrin is traced from Ohio southward into Kentucky. Thus, like the Chattanooga Shale, the stratigraphic subunits of the Ohio Shale in Ohio are similar to those in Kentucky.

It is suggested that the Devonian shale nomenclature for Ohio be revised to show that the Huron Shale is separable into three subunits and that this nomenclature be extended into Kentucky. This is preferable to using Tennessee stratigraphic terminology for Kentucky strata because the Ohio names have priority. It is also suggested that the Cleveland, Chagrin, and Huron be better defined from the subsurface of Ohio to facilitate the construction of cross sections to show the regional relationships between the Devonian shales of Ohio and Kentucky. The importance of subsurface stratigraphy is stressed because outcrop sections are not always complete and may not be spaced closely enough to allow firm correlations.

#### URANIUM IN DEVONIAN BLACK SHALES

The amount of uranium in the black, organic-rich shales of the Upper Devonian shale sequence of the Appalachian Basin is greater than that contained in an average shale by as much as ten times (Turekian and Wedepohl, 1961, Table 2). Consequently, these black shales have been studied as a source of uranium. Such investigations include detailed studies of one formation, like Conant and Swanson's (1961) report on the Chattanooga Shale of Tennessee, and more general accounts of uranium from many different shales of Devonian and other ages (Swanson, 1956; 1960a). No evaluation, however, exists of the uranium reserves in the Ohio Shale in northeastern Kentucky, where outcrops of Devonian black shale may be close to 200 feet in thickness.

How does the uranium potential of the Ohio Shale in Kentucky compare with that of the Ohio's equivalent in Tennessee, the Chattanooga, as reported by Conant and Swanson (1961)? To answer this question, 101 samples of Ohio Shale and its equivalents from Kentucky, Ohio, Tennessee, and Alabama were analyzed for uranium (fig. 3). Fourteen of these were core samples; the remainder were from outcrops of Devonian Shale (Appendix 2).

The amount of uranium was determined by fluorimetric analysis, in which each sample was dissolved in a mixture of nitric, perchloric and hydrofluoric acids and then mixed with aluminum nitrate. To this mixture, ethyl acetate was added, which extracts uranium. Evaporation of the ethyl acetate layer and addition of flux followed by heating produced a pellet of sample whose fluorescence was measured with a fluorimeter. From fluorescence measurements, the amount of  $U_3O_8$  (ppm) was calculated for each sample.

The amount of uranium ranges from 1 to 106 ppm (fig. 15 and Appendix 2) and varies geographically (fig. 16). Such variation is in agreement with results of Conant and Swanson (1961) and Breger and Brown (1963), who both show a decrease in uranium content northward from Tennessee.

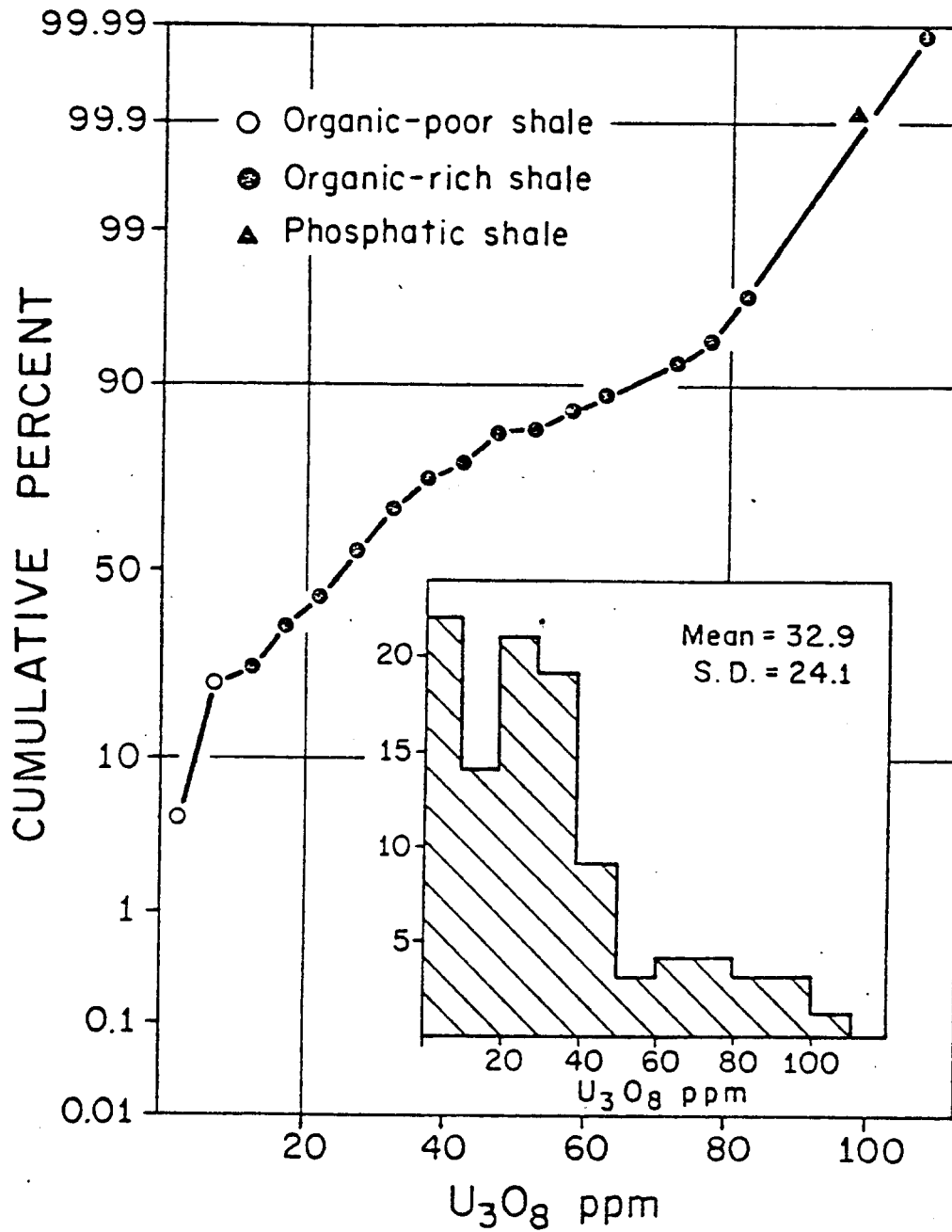


FIGURE 15. --Cumulative curve and histogram of uranium content of 103 samples of Devonian-Mississippian black shale from Ohio, Kentucky, Tennessee, and Alabama.

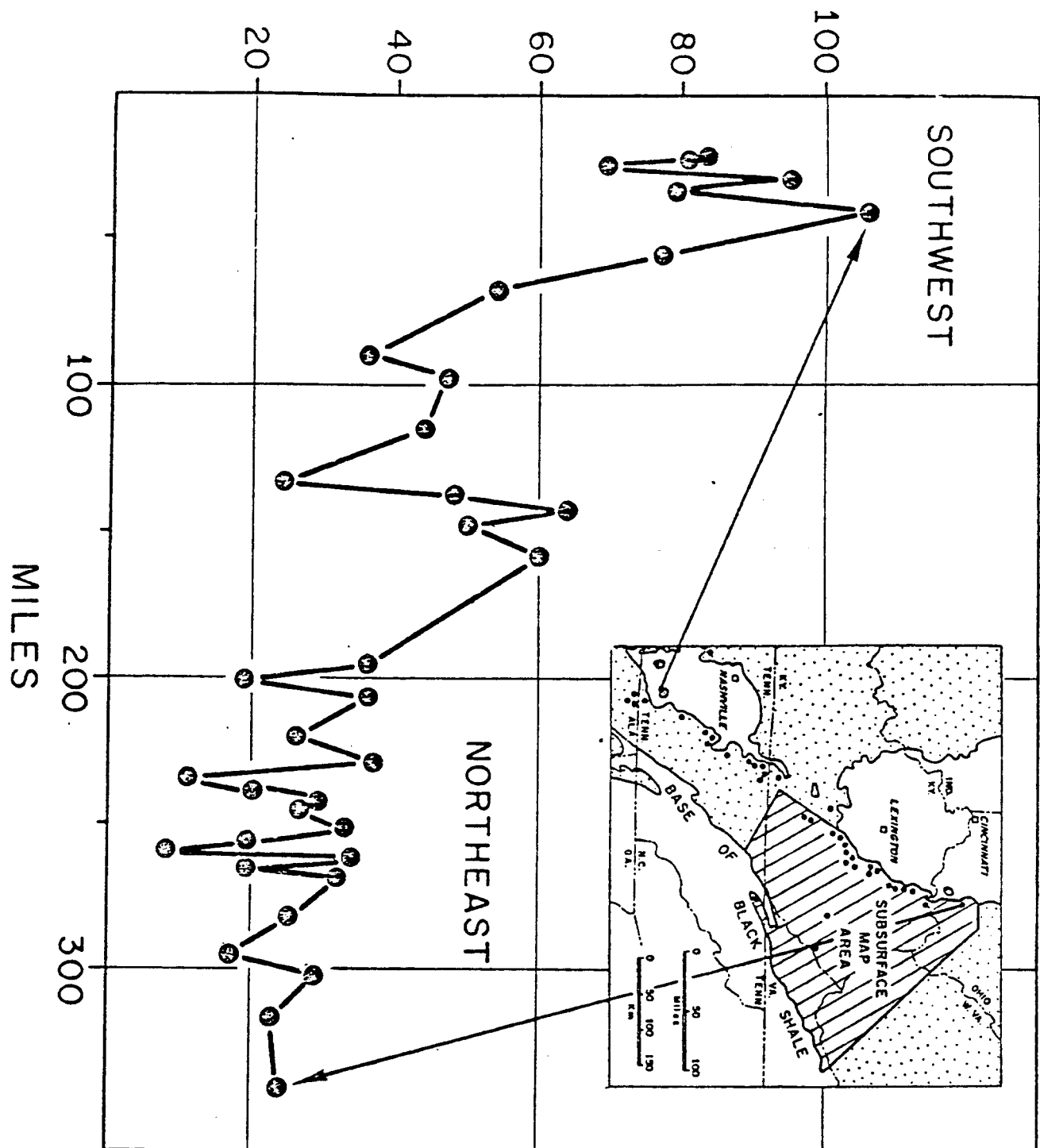


FIGURE 16. --Variation of uranium content of Devonian-Mississippian black shales with position in basin. Samples from the southwestern portion of the Appalachian Basin contain more uranium than those from the central portion of the basin, a phenomenon probably related to the total amount of and the type of organic matter in these black shales. Organic geochemical analyses to determine the precise relationship between uranium and organic matter are currently in progress.

Two important questions are suggested by figures 15 and 16. First, what sort of variation in uranium content is there vertically throughout the seven units of the Ohio Shale in Kentucky? And, what are the reasons for regional and stratigraphic variations in uranium content?

For the Cleveland Shale, Three Lick Bed, and the total Huron Shale of the Ohio Shale in Kentucky, the average amount of uranium per unit is about 30 ppm (Table 3), with the exception of the Three Lick Bed, which contains only 15 ppm. Average uranium content for all samples from the Cleveland, Three Lick, and Huron is 27.7 ppm. The Olentangy and Marcellus (?) Shales are excluded from Table 3 because of the low (typically less than 10 ppm) uranium content of the Olentangy and lack of samples from both units -- they rarely occur at the surface. The greatest range in values from a single unit, 67 ppm, occurs in the Lower Huron Shale (Table 3). In general, uranium content varies little from one stratigraphic unit to the next, provided lithologies of each unit are similar.

An illustration of the effect of lithology on uranium content is seen in the Three Lick Bed. The low average uranium content of this unit can be attributed to the relative abundance of greenish-gray, organic-poor shale in it (fig. 7 and Table 1), but black, organic-rich shale from this unit contains about the same amount of uranium as those units containing abundant black shale (Appendix 2, samples 19899 and 19903).

The total tonnage of uranium per unit for the Cleveland Shale, Three Lick Bed, and total Huron Shale of the Ohio Shale was calculated, using the values of uranium in Table 3. For Kentucky east of longitude  $84^{\circ} 20'$  west, the volume of rock in each unit was obtained from isopach maps of these units (figs. 8 through 12) by finding the area between each contour line with a planimeter and multiplying that area by the average thickness of the contour interval.

Because the concentration of uranium in each unit is nearly equal, the thicker units (Cleveland, Middle and Lower Huron) obviously constitute the greatest source of uranium. The total amount of uranium contained in the uppermost five units of the Ohio Shale in eastern Kentucky is estimated to be  $6.28 \times 10^{12}$  tons (Table 3). In comparison, the Gassaway member of the Chattanooga Shale in eastern Tennessee, whose average thickness is only 15 feet, contains about  $4.5 \times 10^6$  tons of uranium (Conant and Swanson, 1961, p. 76).

As a further illustration of the effect of stratigraphic thickness on uranium reserves, the tonnage of  $U_3O_8$  per square mile was computed for shale sampled from outcrops and core ranging from less than 20 feet to over 300 feet in thickness (fig. 17). Tonnage of uranium was calculated for the entire Ohio (Chattanooga) Shale but not for individual stratigraphic sub-units. For samples from different but nearby outcrops having the same thickness, uranium concentration was averaged to obtain a single, representative value.

TABLE 3. -- Average uranium content and total amount of uranium per unit for the Ohio Shale in eastern Kentucky<sup>1</sup>

UNIT	Arithmetic Average Uranium Content (ppm)	Sample Size	Range in Uranium Content (ppm) with Standard Deviation	Volume of Shale (cu.mi.)	Total Uranium per Unit (tons x 10 <sup>12</sup> )
CLEVELAND SHALE	28.9 ±6.4	10	19 - 48 S.D. = 11.1	115	1.23
THREE LICK BED	15.2 ±8.0	6	6 - 28 S.D. = 9.7	61.4	0.65
UPPER HURON SHALE	31.0 ±6.1	4	26 - 36 S.D. = 5.2	84.7	0.90
MIDDLE HURON SHALE	30.5 ±12.2	6	6 - 47 S.D. = 14.8	146.2	1.56
LOWER HURON SHALE	31.1 ±10.1	10	7 - 74 S.D. = 17.5	182.5	1.95
Total Uranium in Ohio Shale					6.28
<sup>1</sup> Tons of uranium were calculated using a density of 2.3 for the shale. Confidence limits for average uranium content are 90 percent.					

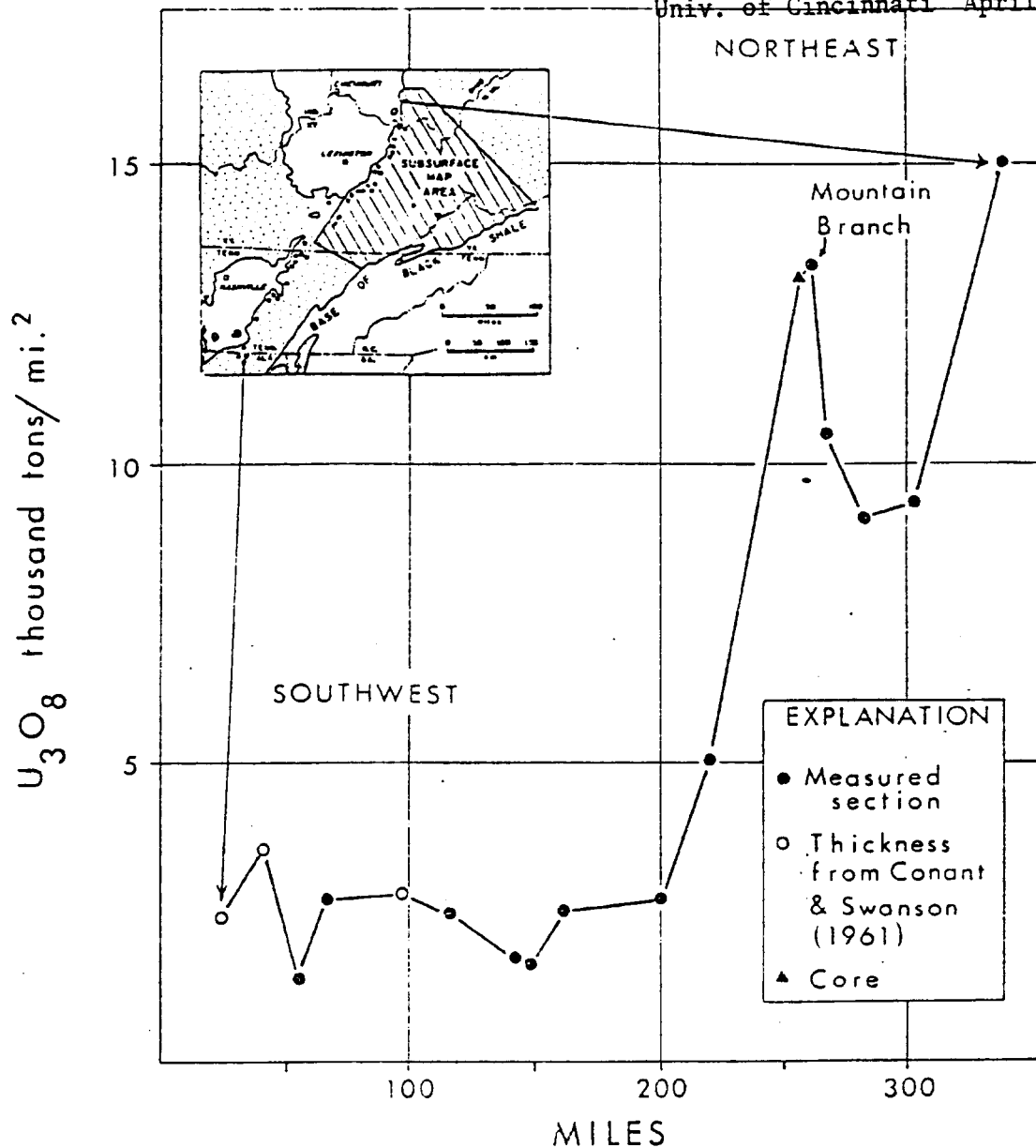


FIGURE 17. --Variation of uranium tonnage per unit area in Devonian-Mississippian black shales with position in basin. Although shale from the southwestern portion of the study area contains up to 106 ppm U<sub>3</sub>O<sub>8</sub> (see figure 16), its thinness results in a low tonnage of uranium per square mile. Where outcrop thickness exceeds 100 feet, the amount of uranium per unit area increases greatly, reaching a maximum of slightly more than 15,000 tons per square mile in southern Ohio, where average uranium content of individual samples is only 25 ppm.

Although the Chattanooga Shale in southern Tennessee and northern Alabama contains from 70 to 100 ppm  $U_3O_8$  (fig. 16), its thinness contributes to its relatively low tonnage of uranium per unit area, generally less than 3,000 tons per square mile (fig. 17). In northern Kentucky and southern Ohio, however, the amount of uranium per square mile increases to a maximum of about 15,000 tons per square mile (fig. 17), more than five times as much uranium as contained in thin exposures to the south. The unusually thick exposure of Ohio Shale at Mountain Branch in eastern Kentucky (Appendix 1, section 10) is estimated to contain over 13,000 tons of uranium per square mile even though no samples from that outcrop contain more than 20 ppm  $U_3O_8$ . Thus, both thickness and uranium concentration must be considered to make a proper evaluation of uranium reserves for the Devonian-Mississippian shales in the central Appalachian Basin. And clearly, per square mile of surface area either strip-mined or mined by some method of underground leaching, eastern Kentucky is superior to Tennessee.

What stratigraphic and regional trends are suggested by the data in Table 3 and figures 16 and 17? First, for the Ohio Shale in Kentucky, there is little variation in average uranium content between each stratigraphic subunit. The highest amounts of uranium are found in the Lower Huron Shale, low in the section. It is also this interval on gamma-ray curves which is most radioactive. Conant and Swanson (1961), however, found that the upper half of the Chattanooga Shale in Tennessee was more uraniferous than the lower.

Secondly, although the Ohio Shale in Kentucky is much thicker than its partial equivalent in Tennessee (the Gassaway member), it is less rich in uranium, the average content being 30 ppm. A typical sample from the Gassaway member contains 60 ppm (Conant and Swanson, 1961, p. 71). This decrease in uranium content northward along the outcrop from Tennessee is illustrated in figure 16. As outcrop thickness increases in the same direction, however, the amount of uranium per square mile also increases from less than 1,500 tons per square mile to over 15,000 tons per square mile (fig. 17).

Finally, the amount of uranium varies with lithology across the central Appalachian Basin in Kentucky. Samples from the measured section at Mountain Branch in Pike County, Kentucky (fig. 2; Appendix 1, section 10) consisted of greenish shales and thin siltstone beds, in addition to black, organic-rich shales. These samples contained significantly less uranium than samples from outcrops along the western edge of the basin (fig. 16; Appendix 2, samples 19906-19920). Furthermore, even the dark shales from Mountain Branch, unlike those from outcrops to the west and north, contained no more than 18 ppm of uranium. Similarly, Conant and Swanson (1961) noted that gray shales and sandstone in the Chattanooga Shale of Tennessee had the least uranium, while black shales had the most.

## DEPOSITION OF BLACK SHALE AND THE ORIGIN OF URANIUM

As shown earlier, lithology and position within the basin influence the amount of uranium in the Upper Devonian black shale of the central Appalachian Basin. Lithology, in turn, is partly controlled by depositional environment, while position within the basin can be a direct indication of depositional environment. What was there about the environment in which black, organic-rich muds accumulated during Late Devonian time that would also favor the accumulation of greater than normal amounts of uranium? Because uranium is most abundant in those shales rich in organic matter, the first step is to determine the reasons for accumulation of organic matter in the Upper Devonian shale sequence.

The two most important factors controlling the presence of organic matter in sediments -- be they sands, silts, or muds -- are production and preservation of abundant organic matter. Organic matter, represented simply as carbon, may be carried into the basin by streams. Added to this terrestrial supply is organic matter produced by death of marine plants and animals and bacteria within the basin.

Organic-rich sediments, however, depend on more than production of organic matter. Organic matter must also be preserved, generally by certain chemical and physical characteristics of the water mass which prevent destruction of organic material. The water mass must also have a density stratification. Such a stratification weakens circulation, especially the exchange of oxygen, and, in turn, inhibits oxidation of organic matter and creates in the water mass conditions unfavorable or even toxic to marine life. In addition, the amount of clastic sediments entering the basin must be relatively low to prevent dilution of organic matter by mud, silt, or sand. For the Ohio Shale and its equivalents, clastic input consisted almost exclusively of fine-grained sediments, suggesting that deposition occurred far from areas that could contribute coarse-grained detritus.

The association of uranium and organic matter in shales has been noted in many studies (Brown, 1956, p. 461; Swanson, 1956, p. 454, 1960a, pp. 78, 86, 1960b, fig. 2; Kepferle, 1959, p. 602; Conant and Swanson, 1961, p. 73; Breger and Brown, 1963, p. 753). In fact, organic matter is generally believed to complex and retain uranium -- carried to depositional sites by streams or existing as a normal constituent of seawater -- from sea water (Conant, 1956, p. 466; Breger and Brown, 1963, pp. 752, 754). Variations in uranium content vertically throughout the Ohio Shale section, as discussed earlier, are likely related to lithology, especially the proportion of organic matter to detrital matter. The relationship of lithology (including organic components) to uranium suggests that certain sedimentological processes, in part, should govern the concentration of uranium in a sediment much as they govern rock type.

What sedimentological processes were operating during deposition of the Ohio Shale? In other words, what was the depositional environment of these black, organic-rich shales of the Upper Devonian?

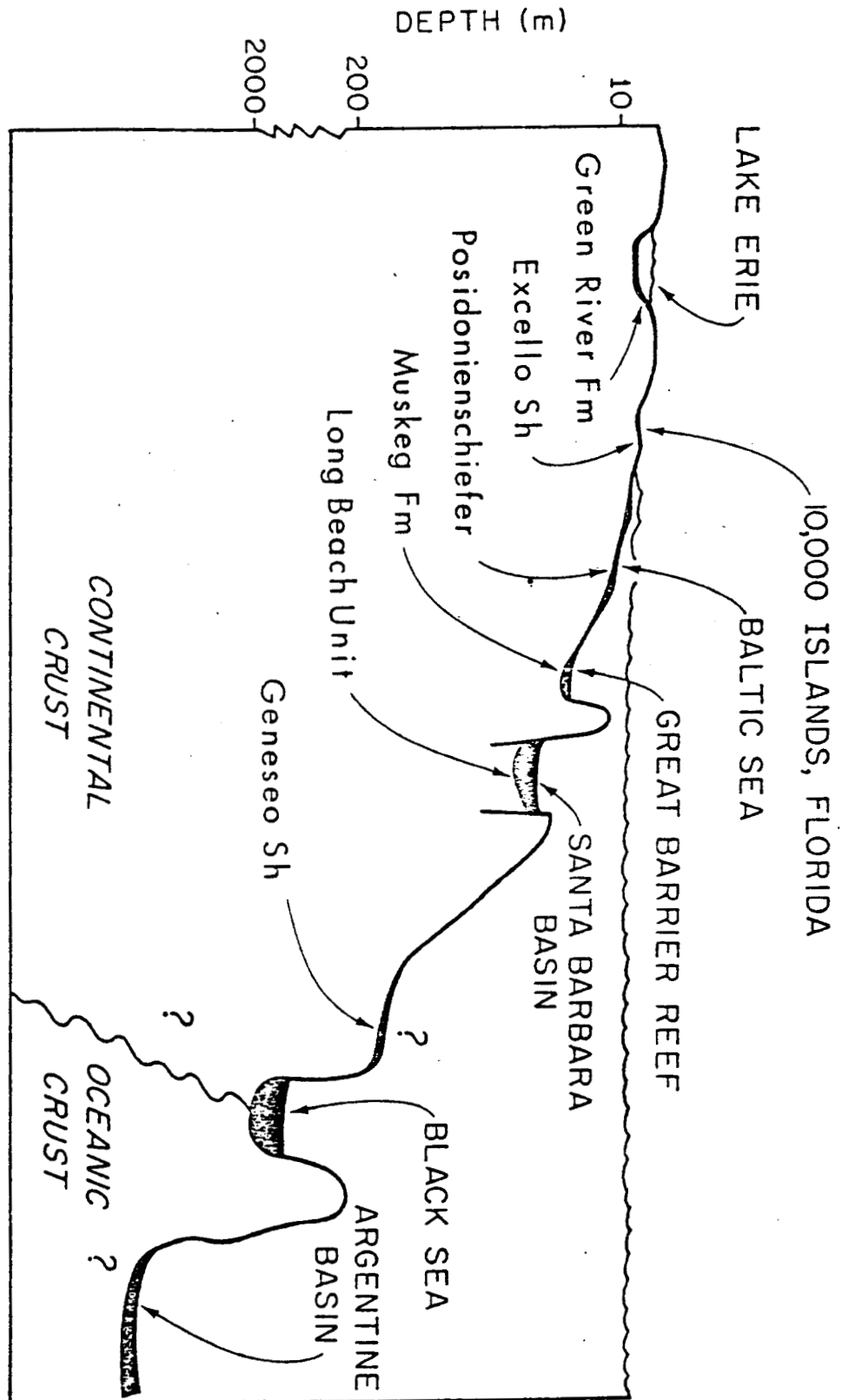


FIGURE 18. --Schematic diagram of modern and ancient environments in which black mud is accumulating. (Ancient environments shown in lower case letters.) The Ohio Shale and its equivalents probably were deposited in environments similar to the Baltic Sea and the Genesee Shale, with water depths ranging from less than 100 feet to several hundred feet.

In attempting to answer those questions, one immediately faces two additional questions: (1) is there a modern analogue for the Ohio Shale? and (2) where else are black shales of Devonian or other ages found? This approach to interpreting depositional environment for the Ohio Shale is necessary largely because of lack of features such as sedimentary structures and vertical sequences which usually help to identify depositional settings.

Modern environments where black mud is accumulating were discussed by Strom (1939) and Twenhofel (1939). These authors, through examples, showed that black muds may be deposited under marine and non-marine conditions, from very shallow (a few feet) to abyssal depths, in small restricted bays or over large areas (fig. 18). Thus, there is a wide range of modern environments which may represent the type of sedimentation which occurred in the central Appalachian Basin during Late Devonian time.

One modern depositional setting for Devonian-Mississippian black shale, as suggested by Breger and Brown (1963, p. 745), are salt marshes along the Gulf Coast of Louisiana, where organic matter is abundant and current action is not particularly vigorous. These authors maintain that similar conditions characterized deposition of the Chattanooga Shale over much of Tennessee. A second modern environment where black mud is being deposited (fig. 18) occurs along the eastern Baltic Sea (Twenhofel, 1939). This environment, however, is generally much like that found along the Louisiana coast, and both of them, therefore, are possible modern analogues for the Chattanooga and Ohio Shales.

In comparing sedimentation along these modern coastal regions with that which occurred during Late Devonian-Early Mississippian time in the western, central, and southern Appalachian Basin, two differences stand out. First, the area occupied by modern salt marshes is far less than that where Devonian-Mississippian black shale is known to occur in North America, estimated to be over 500,000 square miles. In the Appalachian Basin alone, black shale of Devonian-Mississippian age extends from New York to Alabama (Conant and Swanson, 1961, pl. 14). Secondly, water depths along the Gulf or Baltic coastal areas do not have as great a range as water depths for Devonian-Mississippian black shale, which probably attained a maximum of a few hundred feet in western New York State as inferred from the association of black shale and prodeltaic siltstone and shale (Rickard, 1964; Sutton, 1963, fig. 2, pp. 96-97; Sutton, Bowen, and McAlester, 1970, fig. 7).

Neither of these differences between modern and ancient settings of black shale deposition is significant enough to invalidate the analogy of modern coastal areas to Devonian-Mississippian sedimentation in the Appalachian Basin. Such differences simply mean that, in the late Paleozoic, the areal extent of black mud accumulation was far greater than in any modern areas receiving similar sediments. Differences in water depth are not critical, provided conditions for production and preservation of organic matter are met. Lineback (1968, p. 1301), for example, suggests that a dense, floating mat of algal material could have simultaneously been the source of organic matter in the New Albany Shale of Indiana and the means for restricting circulation, producing an environment favorable to the preservation of organic matter.

In determining a suitable modern analogue for the Ohio Shale, one must also consider the regional equivalents of the Ohio Shale in the Appalachian Basin. In the eastern half of the Appalachian Basin, Upper Devonian rocks consist primarily of sandstone and siltstone deposited in a complex deltaic environment (Dennison, 1971, p. 1181). Although black, organic-rich shale is generally confined to the western portion of the basin, thin tongues of black shale (e.g., Genesee Shale, fig. 18) extend eastward, where they are contained within prodeltaic (slope and basin) siltstone and mudstone (Rickard, 1964; Sutton, 1963, fig. 2, pp. 96-97; Sutton, Bowen, and McAlester, 1970, fig. 7) and within lighter-colored shale and mudstone (Lewis and Schwietering, 1971, figs. 2, 4.b). The widespread distribution of black shale the same age as the Ohio Shale, extending in the Appalachian Basin from New York to Alabama (Conant and Swanson, 1961, pl. 14) suggests that prodeltaic siltstone and mudstone such as observed in outcrop in New York may also occur in the subsurface of Pennsylvania, West Virginia, and other states to the south. No modern analogue for the Genesee and related shales in New York (Table 4), however, exists.

Upper Devonian black shale is not limited to the Appalachian Basin, but has been reported from basins lying far to the west and to the north. Moreover, black shale is not exclusively characteristic of North American Upper Devonian sequences, but also occurs on three other continents: South America, Africa, and Europe (Table 4). Considering the widespread geographic occurrence of Upper Devonian black shale, it is reasonable to expect that these shales may represent more than one depositional environment, including prodelta (Table 4, Dunkirk and other shales); shallow epicontinental sea (Conant and Swanson, 1961; Lineback, 1968); lagoon (Table 4; MacQueen and Sandberg, 1970); deep basin (Table 4; Ludwig, Schmitz, and Mayer, 1968); and basins adjacent to reefs (Table 4; Krebs, 1969). Unfortunately, little is known about depositional setting of black shale outside of North America.

In the area studied, deposition of the Ohio Shale probably occurred in a shallow epicontinental sea which lay to the west of prograding delta systems originating in New York, Pennsylvania, and Virginia (Dennison, 1971, p. 1189). Water depths could have ranged from several tens of feet along the western margin of the Appalachian Basin where the Cincinnati Arch influenced sedimentation (Lewis and Schwietering, 1971, p. 3482) to a few hundred feet where black shales are associated with prodeltaic turbidites. Other requirements for deposition and preservation of Upper Devonian black shales include production and preservation of organic matter, a stratified water mass, and low clastic input. Periodically, improved circulation and increased clastic input resulted in deposition of greenish-gray, organic-poor shale, possibly in response to turbidity currents elsewhere in the basin. A decrease in production of organic matter could also be a factor controlling deposition of these non-black shales but is not a necessary assumption.

For black shales deposited in the central Appalachian Basin during Late Devonian-Early Mississippian time, one of the principal factors controlling the amount of uranium is the amount of organic matter. Shales

TABLE 4. -- Annotated references to Devonian black shales worldwide,  
with formation names and basins in which they occur

PART A: NORTH AMERICA

FORMATION	BASIN	REFERENCE
OHIO SHALE	Appalachian	Hoover, 1960  Defines internal stratigraphy of outcropping Devonian shales in Ohio and recognizes three members: the Cleveland, the Chagrin, and the Huron.
DUNKIRK, PIPECREEK, RHINESTREET, MONTGOMERY, and GENESEE SHALES	Appalachian	Rickard, 1964  A correlation chart of Devonian rocks in New York, which nicely shows the relationship of these thin black shale tongues to grey shales and siltstones of the Catskill delta.
HARRELL SHALE	Appalachian	Dennison & Head 1975  A long review of evidence supporting sealevel fluctuations in the Appalachian Basin during Silurian and Devonian. Much information on stratigraphy, sedimentation, and tectonics. A good place to start when a regional synthesis is needed.
CHATTANOOGA SHALE	Appalachian	Conant & Swanson 1961  An exhaustive study of the "type" black shale in Tennessee, including sections on stratigraphy, age, mineralogy, paleontology, structure, tectonics, economic geology and paleogeography. The authors recognize five members and two lithologies in the standard section, and map the distribution of stratigraphic equivalents of the Chattanooga in the U. S.
NEW ALBANY SHALE	Illinois	Lineback, 1968  An article of regional interest, which accomplishes two things: (1) revision of New Albany Shale stratigraphy; (2) interpretation of depositional environment. Suggests a floating algal mat ("flotant") produced organic matter and restricted circulation.
ANTRIM SHALE	Michigan	Cohoe & Others 1951  An older but excellent set of maps, cross sections, and gas production data.

TABLE 4. -- Annotated references to Devonian black shales worldwide,  
with formation names and basins in which they occur -- Continued

PART A: NORTH AMERICA -- Continued

FORMATION	BASIN	REFERENCE
LONG RAPIDS FORMATION	Moose River	Sanford & Norris 1973 Part of a series of articles on future petroleum provinces in Canada. Here, black shale yields oil.
SHEFFIELD SHALE	Forest City	Collinson, 1967 A regional study of Devonian rocks from Indiana to Nebraska by a conodont expert, with detailed correlation chart and several cross sections.
CHATTANOOGA SHALE	Salina	Lee, 1956 Stratigraphic and structural history of this basin by a long- time student of Kansas geology.
WOODFORD SHALE	Ouachita- Arkoma	Amsden & Others, 1967 Amsden & Klapper, 1972 These two papers, by a midcontinent stratigrapher and a conodont biostratigrapher, give much stratigraphic data for the Oklahoma area. Interesting discussion of a producing, basal sandstone to the black shale.
DOUBLEHORN SHALE	(Texas)	Cloud & Others, 1957 A short account of Devonian-Mississippian transitional rocks in Texas described from thin (15 ft.), scattered surface exposures near the Llano Uplift.
PERCHA SHALE	Tobosa	Kottlowski, 1963 Comprehensive review of Paleozoic and Mesozoic rocks in southern New Mexico. Describes a facies change within this black shale.
BAKKEN FORMATION	Williston	Kents, 1959 Saskatchewan stratigraphy. Shale sequence enclosed between two carbonate sequences. Many subsurface maps. Suggests new exploration objectives based on structural features.
PILOT SHALE	Great	Sandberg & Poole, 1975 Part of an investigation of source rocks in the Great Basin, Utah-Nevada. Here, carbonaceous shale intertongues with turbidites and debris-flow deposits. Some data on organic carbon content, soluble hydrocarbon content, and maturation.

TABLE 4. -- Annotated references to Devonian black shales worldwide,  
with formation names and basins in which they occur -- Continued

PART A: NORTH AMERICA -- Continued

FORMATION	BASIN	REFERENCE	
SAPPINGTON MEMBER	Williston	Gutschick & Rodriguez 1975	Although this paper's first purpose is to summarize brachiopod faunas of the Sappington, it also contains a useful stratigraphic column and correlation chart. Regional surface and subsurface correlation substantiated by fossil data demonstrates that dark shale in Sappington is equivalent to Exshaw of Alberta. Thirty references on northern Rockies stratigraphy and biostratigraphy.
EXSHAW SHALE	Williston	MacQueen & Sandberg 1970	Lithology, mineralogy, stratigraphic relations, and biostratigraphy of a thin Devonian-Mississippian black shale of western Canada. Based on 20 measured sections. Suggest that deposition occurred in shallow marine, euxinic lagoons.
BESA RIVER SHALE	Northeast British Columbia	Pelzer, 1966	Predominantly a geochemical study of this British Columbian black shale with some stratigraphy and biostratigraphy. One of the thickest North American black shales (3,000 feet).
CANOL FORMATION	Peel- Anderson	Bassett, 1961	One of many papers in a volume of Arctic geology. Suggests the stratigraphic relations of this unit may be similar to those of the Exshaw.
FORD LAKE SHALE	Eagle- Kandik	Brabb, 1969	Brief mention of a thick transitional Devonian-Mississippian black shale in Alaska.
KAYAK & HUNT FORK SHALES	North Slope	Bowsher & Dutro 1957	Two papers containing most of what is known about Paleozoic stratigraphy in Alaska's Brooks Range. Dark shale and argillite up to 1,000 feet thick.

PART B: OTHER CONTINENTS

SOUTH AMERICA		
Rincón Formation Tonono Formation	Salteño	Mingramm & Russo 1972
		Lower and Middle Devonian black shales - Upper Devonian rocks are missing here. Correlation chart for Argentina, Paraguay, and Bolivia.

PART B: OTHER CONTINENTS -- Continued  
SOUTH AMERICA -- Continued

TABLE 4. -- Annotated references to Devonian black shales worldwide,  
with formation names and basins in which they occur -- Continued

FORMATION	BASIN	REFERENCE	
LONGÁ SHALE	Maranhão	Mesner & Wooldridge 1964	Good summary of Brazilian Paleozoic and Mesozoic paleogeography with detailed lithologic column for this basin. Authors correlate this basin with three others in Brazil. Figure 21 shows that most of South America (except for this basin) was emergent during Late Devonian.
PONTA GROSSA FORMATION	Parana	Lange & Petri 1967	The Ponta Grossa, Middle to Late Devonian in age, has 20 m of black shale at top. Thickens greatly to the northwest, attaining a thickness of 5,000 m in the Bolivian Andes.
BARREIRINHA SHALE	Amazon	Morales, 1959 Ludwig, Schmitz, & Mayer 1968	Two papers - one in English, the other in Portuguese - which nicely describe the Paleozoic history of this basin. The more recent paper is a detailed facies analysis of this formation and contains much analytical data on this important source bed. Suggest deposition was in a deep marine basin.
AFRICA BOKKEVELD & WITTEBERG SERIES	Cape	DeVilliers, 1967	A brief, general paper from the 1967 Symposium on the Devonian held in Calgary. Not much is known about these groups, sequences of clastic rocks which contain black shale.
DRA FACIES	Tindouf	Hollard, 1967	Only one or two paragraphs briefly mentioning this black shale found in northwestern Africa. About 150 m thick.
UNNAMED BLACK SHALE	Oued Mya & Oued Rhir	Ortynski, Perrodon & delapparent, 1959	Review of paleogeography and structural history of Paleozoic and Mesozoic basins in northern Sahara, where black shale, black limestone, and sandstone characterize Frasnian and Famennian rocks.

TABLE 4. -- Annotated references to Devonian black shales worldwide,  
 with formation names and basins in which they occur -- Continued

PART B: OTHER CONTINENTS -- Continued

FORMATION	BASIN	REFERENCE
<u>EUROPE</u> Hunsrück Budesheim Nehden Wissenbach Flinz Kellwasserkalk	Variscan	Krebs, 1969  Many of these German black shales are associated with carbonate reefs and have limited distribution, while others are thin and areally extensive and may represent initial deposits of transgressing seas.
DOMANIK FACIES	Russian Platform	Nalivkin, Rzhonsnltzkaya, & Markovskii, 1973  895 pages on Devonian stratigraphy and paleontology of the Soviet Union. Two volumes, in Russian. This sequence of Frasnian bituminous shale and limestone from the area near Moscow ranges from 100-300 feet in thickness.

which were deposited in areas where organic matter was oxidized or diluted by clastic sediments have low concentrations of uranium. However, there must be another factor influencing the amount of uranium because even the organic-rich shales from eastern Kentucky contain less uranium than similar shales from Tennessee.

The relationship between the amount of organic matter and geography and uranium content of Devonian black shales suggests three questions. Did the rate of sedimentation vary throughout the basin, thus allowing more time for extraction of uranium from seawater by organic matter in areas of slow sedimentation? Did more uranium enter the depositional basin in Tennessee than in Ohio and Kentucky because of streams carrying high amounts of uranium? Or does the type of organic matter as well as its absolute amount influence the concentration of uranium in Devonian black shales?

To answer these questions, three types of organic geochemical analyses are now being done on samples collected for this report: (1) amount of organic carbon; (2) amount of extractable organic matter; and (3) stable isotope ratios ( $C^{12}/C^{13}$ ). These new analyses will provide a better understanding of sedimentological processes which control uranium concentration.

First, determining the amount of organic carbon and extractable organics should show how these two variables correlate with uranium concentration. In addition, these two variables will provide a better geochemical characterization of black shale; in this report, this was estimated by lithology (color) and stratigraphy. Second, stable isotope ratios ( $C^{12}/C^{13}$ ) indicate whether the organic matter in the shale was of marine or terrestrial origin (Degens, 1969) and, thus, should allow evaluation of the influence of the type of organic matter as well as its absolute amount. These ratios likely vary throughout the basin with depositional setting and, therefore, determination of these ratios should improve prediction of uranium trends. Finally, these organic geochemical analyses make it possible to compare this study with others of uranium geochemistry. The results of these analyses, as soon as they are completed, will be included in a supplement to this report.

#### EVALUATION OF PROGRESS IN THIS AREA OF RESEARCH

During the past two years, four aspects of Devonian black shales of the central Appalachian Basin have been investigated: (1) stratigraphy, (2) sedimentology, (3) geochemistry (uranium and organic), and (4) resource potential for uranium. The basic tools for studying this shale sequence -- its internal stratigraphy and lithologic types -- have evolved from research done for this report. Literature study of Devonian black shales worldwide has provided models of depositional settings of black shale and of the origin of black muds. And, the amount of uranium contained in Devonian black shales has been estimated for eastern Kentucky.

More work is needed, however, on the relationship of organic matter and uranium content, particularly the effect of type of organic matter on uranium enrichment. Organic geochemical analyses are presently being

performed on some of the shale samples used in this report; from these, we hope to define more precisely the relationship of uranium and organic matter in Devonian black shales. If Devonian black shales are to be exploited for uranium, additional, more technological questions of mining methods, extraction, and environmental effects must be posed and answered. These questions are not addressed in this report, but it is suggested that research programs be set up to investigate problems of using the black shale as a source of uranium. Finally, the internal stratigraphy developed for this portion of the Appalachian Basin should be extended to the north and east to show better the relationships between black shale and its equivalent lithofacies throughout the basin. Work is in progress to establish these relationships.

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APPENDIX 1--DESCRIPTIONS OF THE TEN MEASURED SECTIONS  
 OF THE OHIO AND CHATTANOOGA SHALES OF THIS  
 REPORT

SECTION 1

Copperas Mountain Section

Nearly complete section of Ohio Shale in a spectacular exposure, where Paint Creek impinges at base of and undercuts Copperas Mountain in Ross County, Ohio, approximately 3.9 airline miles east of Bainbridge by way of U.S. Highway 50, Jones Levee Road and Storm Station Road, on the Morgantown 7.5' Quadrangle (1,802,300 feet east, 450,000 feet north, Ohio coordinate system, south zone). Because of the steep slopes and cliffs, we could only obtain detailed lithologic observations at considerable hazard; and, consequently, the section was described in reconnaissance only except for some details of the Three Lick Bed. However, the section is notable for the outstanding exposure of the Three Lick Bed, which can be seen from afar when driving east on U.S. Highway 50 from Bainbridge, and for its unique system of buttresses. Described with Jacob's staff, Abney level, and tape by Roy C. Kepferle, J. Barry Maynard, Paul Edwin Potter, Wayne A. Pryor, and Rene Ulmschneider on August 31 and September 8, 1976. Scintillometer survey was made on August 31.

	Thickness (feet)
Mississippian:	
Berea Sandstone (incomplete):	
6. Sandstone, weathers yellowish gray and iron-stained and fine in dense, hard resistant beds 0.2 to 0.4 foot thick; sole marks include grooves and trace fossils. Slightly slumped; caps ridge. . . . .	2.0+
Bedford Shale:	
5. Shale, mainly covered except for lower part, which is partially exposed in a slump scar near the top of the cliff about 100 feet north of the trail. Sandstone in float in slump scar is thin-bedded and rippled and has numerous sole marks as is typical of the Bedford; mudstone is greenish gray with iron-stained siltstone concretions near base. Sharp basal contact is well exposed at base of scar but is partially covered at the highest point of the cliff 285 feet above low-water Paint Creek. . . . .	83.0
Total Mississippian (incomplete) . . . . .	<u>85+</u>

Devonian:

Thickness  
(feet)

Ohio Shale (incomplete):

4. Shale, brownish-black and blocky, forming a near vertical, jagged cliff easily seen from river level. Sharp basal contact. . . . . 65

Three Lick Bed:

3. Mudstone and shale. Mudstone is greenish gray, weathers soft and contains minor pyrite. Shale is brownish black and forms thin fissle ledges. The mudstone forms three prominent beds; the upper is 5.0 feet, the middle is 1.7 feet, and the basal bed is 4.8 feet thick; the upper intervening black shale is 4.2 feet thick and split by a thin cone-in-cone limestone bed near its middle; the lower intervening black shale is 4.8 feet thick and contains several thin, greenish-gray mudstone beds . . . . . 20.5

Total Three Lick Bed . . . . . 20.5

2. Shale, brownish-black, weathers to very steep flumes, many of which have thin, near vertical spectacular buttress-like divides. (We have not seen erosional patterns like this although they are reportedly common in parts of New York in the Upper Devonian shale sequence.) These buttresses extend nearly vertically from the base of the exposure to about 140 feet above Paint Creek, and then rise at about an angle of 30° up to the Three Lick Bed. Above this break in slope there is a distinct, regular banding characterized by couplets of resistant and nonresistant shale; the latter is recessive and accumulates a fine talus of light-gray weathered shale chips. Two thin, easily seen cone-in-cone limestone beds occur at 11 and 41 feet below the base of the Three Lick Bed; 35 feet below the Three Lick Bed is another less continuous thin cone-in-cone bed of limestone. About 65 feet above Paint Creek are three small concretions, 1 to 3 feet in size. Near the road, 15 to 25 feet above Paint Creek, is a zone of very large dolomitic concretions, some of which are hollow and all of which exhibit marked differential compaction in the shale; these concretions range in size from 1 to 6 feet. A thin, greenish-gray mudstone occurs beneath this zone. Some Foerstia were observed in the float near the base of the section . . . . . 190

Devonian (continued):

Thickness  
(feet)

Ohio Shale (continued):

1. Covered to low water Paint Creek. . . . .	10
Total Ohio Shale is approximately . . . . .	<u>275+</u>
Total section is approximately 360 feet thick	

SECTION 2

Tener Mountain Section

Nearly complete section of Ohio Shale, Bedford Shale, Berea Sandstone, and Sunbury Shale exposed for 5.1 miles in roadcuts along both sides of Ohio Highway 32 near Peebles, Franklin Township, Adams County, Ohio. Base of section is on northwest side of Ohio Highway 32 at its junction with Ohio Highway 73 (Jaybird quadrangle), where lowermost 26.5 feet were measured and described. Upper 215.9 feet of section ending at top of Ohio Shale were measured along east side of Ohio Highway 32, (Byington quadrangle). Incomplete exposures of Bedford Shale, Berea Sandstone and Sunbury Shale on west side of Ohio Highway 32 at its intersection with Union Hill Road, 1.15 miles northeast (Byington quadrangle). Section measured, described, and sampled using Jacob's staff, Abney level, aneroid barometer, and tape, and its radioactivity profile measured using scintillometer by R. C. Kepferle, P. E. Potter, Linda J. Provo, and Tom Yu, June 25 and 29, 1976

Thickness  
(feet)

Mississippian (incomplete):

Cuyahoga Formation (incomplete):

38. Siltstone (single bed), weathers yellowish-gray (5Y 8/1); <u>Zoophycos</u> -like burrows on top; limonite stain along joint. Two sets of sole marks at 205° and 280°, with blunter ends toward these directions. Massive bedding, probably Ta interval of Bouma (1962). . . . .	1.3
37. Shale, greenish-gray (5G 6/1), locally blackish-red (5R 2/2) to grayish-red (5R 4/2) higher in unit. Rare, poorly defined siltstone beds, olive-gray (5Y 4/1) to light-brownish-gray (5YR 6/1) with limonitic stain . . . . .	<u>26.0</u>
Total Cuyahoga Formation (incomplete). . . . .	<u>27.3+</u>

Mississippian (continued):

Sunbury Shale:

36. Shale, black (N1) to grayish-black (N2), weathers medium light gray (N6) to yellowish gray (5Y 8/1) where stained with jarosite, grayish-brown (5Y 3/2) to dark yellowish-orange (10YR 6/6) where stained with limonite; fissile, laminated, brittle, no silt. Pyrite nodules, 4 cm., occur 4 feet below top and rarer, smaller (1-2 cm.) pyrite nodules, finely crystalline, lobate, flattened along bedding planes throughout rest of unit. Phosphate nodules, 2-3 cm., ovoid, with fossil core, at top of unit (sampled). Burrows, 4 mm. wide, along bedding planes, fairly straight, filled with light-olive-gray (5Y 6/1) mudstone. Vertical silica "dikey" strikes 25° in ditch on west side of highway, 6-7 cm. wide, limonite-stained (sampled) . . . . . 15.0
35. Siltstone, dark-gray (N3) where carbonaceous, grading to light-olive-gray (5Y 6/1), flecks of carbonaceous material and wispy dark streaks; abundant Lingula fragments. Distinct, irregular contact with less than 1 cm. of dark shale, like unit 36 with thin silt laminae less than 1 mm. thick and a few Lingula fragments (sampled). . . . . 0.05
34. Shale, grayish-black (N2), silty, laminated, pyrite, with very thin laminae of silt one or two grains thick. At top of unit is a trashy zone of Lingula fragments and conodonts (sampled). Basal contact sharp. . . . . 0.05
- Total Sunbury Shale . . . . . 15.1

Berea Sandstone:

33. Sandstone, silty, medium-light-gray (N6) to light-olive-gray (5Y 6/1), weathers grayish-orange (10YR 7/4) to yellowish-gray (5Y 8/1); darker zones near top are pyritic; bed thickness increases upward from 0.7 foot to as much as 4 feet; at top is a 2-4 cm. pyrite bed . . . . . 30.5
32. Sandstone and silty shale in equal amounts. Sandstone is like unit 33, except beds 0.1-0.2 foot thick. Upper bed surfaces are rippled; ripple crests strike 290-310°; wavelength is commonly 10 cm., wave height is commonly 1-2 cm.; cross laminae dip southwest in

Mississippian (continued):	Thickness (feet)
Berea Sandstone (continued):	
lower parts of rippled beds and northeast in upper parts. Shale is greenish-gray (5GY 6/1), silty.	
Contacts sharp. . . . .	<u>14.5</u>
Total Berea Sandstone. . . . .	<u>45.0</u>
Bedford Shale:	
31. Shale (70 percent) and interbedded siltstone and very fine-grained sandstone (30 percent). Shale is greenish gray (5GY 6/1), silty, with some silt laminae. Siltstone and sandstone beds are less than 1 cm. thick, upper surfaces rippled and burrowed; complex burrow system on soles and load and flute casts (?). Amount of siltstone and sandstone increases in overlying units 32 and 33. Offset along basal contact of Bedford Shale 1.16 miles south along east side of Ohio Highway 32. .	20.0
30. Covered interval (thickness approximate) . . . . .	<u>60</u>
Total Bedford Shale . . . . .	<u>80</u>
Devonian:	
Ohio Shale (incomplete):	
29. Shale, dark-gray (N3) to brownish-black (5YR 2/1), weathers to very thin light-gray (N7) chips; brittle, fissile, subconchoidal fracture, tough when fresh, forms massive faces; no silt, pyritic; spores common throughout unit and increase in abundance upward; rare <u>Lingula</u> near upper contact. Uppermost 0.1 foot separated from main part of unit by 0.3 foot yellowish-brown (10YR 6/4) mudstone. Sampled at base and at 20 and 26 feet above base. Contact with underlying unit is sharp and slightly irregular. . . . .	61.1
Three Lick Bed:	
28. Shale, dark-greenish-gray (5GY 4/1) to greenish-gray (5GY 6/1), poorly laminated, soft, non-brittle, clayey; limonitic stain along bedding planes. . . . .	0.3
27. Shale, brownish-black (5YR 2/1), fissile, brittle, slightly silty, pyritic; rare spores. . . . .	0.2

Devonian (continued):

Ohio Shale (continued):

		Thickness (feet)•
Three Lick Bed (continued):		
26.	Shale, dark-greenish-gray (5GY 4/1) to greenish-gray (5GY 6/1), like unit 23. Sampled 0.7 foot below top . . . . .	3.7
25.	Shale, brownish-black (5YR 2/1), like unit 27 . . . . .	4.3
24.	Shale, dark-greenish-gray (5GY 4/1) to greenish-gray (5GY 6/1), like unit 28. . . . .	0.2
23.	Shale, brownish-black (5YR 2/1), like unit 27, slightly mottled. Sampled at base. . . . .	1.1
22.	Shale, dark-greenish-gray (5GY 4/1) to greenish-gray (5GY 6/1), like unit 28; possible pyrite-filled burrows along bedding. Sampled 0.8 foot above base . . . . .	2.2
21.	Shale, brownish-black (5YR 2/1), like unit 27; abundant spores . . . . .	3.0
20.	Shale, dark-greenish-gray (5GY 4/1) to greenish-gray (5GY 6/1), like unit 28; abundant, tiny flecks of black carbonaceous matter. . . . .	0.2
19.	Shale, brownish-black (5YR 2/1), like unit 27; 1 cm. clay shale parting 0.6 foot above base; rare spores. Sampled at 0.2 foot above base. . . . .	1.5
18.	Shale, dark-greenish-gray (5GY 4/1) to greenish-gray (5GY 6/1), like unit 28. Sampled 0.5 foot above base. . . . .	<u>4.4</u>
Total Three Lick Bed . . . . .		<u>21.1</u>
17.	Shale, dark-gray (N3) to grayish-black (N2), weathers light gray (N7) to medium light gray (N6) chips, 1-2 cm; fissile, brittle, uniform, subconchoidal fracture, silty; numerous spores near base, decreasing in abundance upward; abundant flecks of black carbonaceous matter; few pyrite nodules, 2-3 cm., flattened along bedding planes in lower 3 feet of unit; pyritic zone 9 feet below top; two 0.1-foot thick, discontinuous cone-in-cone layers at 22 (sampled) and 33.5 feet below top. Unit weathers in ribbed fashion with ribs 0.5 foot thick separated by talus-covered slopes 0.2 to 0.5 foot thick.	

Devonian (continued):

Thickness  
 (feet)

Ohio Shale (continued):

	Denser, more resistant bed at 40 feet above base. Sampled 6 and 43 feet above base . . . . .	96.0
16.	Shale, dark-greenish-gray (5GY 4/1), thinly laminated, poorly fissile, clayey, cohesive. . . . .	0.1
15.	Shale, dark-gray (N3), fissile, brittle, fine; rare spores. . . . .	1.5
14.	Shale, dark-greenish-gray (5GY 4/1), like unit 16. .	0.4
13.	Shale, dark-gray (N3) to medium-dark-gray (N4), like unit 15. Contact with underlying gray shale sharp .	0.5
12.	Shale, dark-greenish-gray (5GY 4/1), like unit 16. .	0.4
11.	Shale, grayish-black (N2) to brownish-black (5YR 2/1), weathers to thin, small chips less than 1 cm. in diameter; laminated with laminae 1-2 mm. thick; poorly fissile, fine, pyritic; spores common to rare. . . .	1.1
10.	Shale, greenish-gray (5GY 6/1) to dark-greenish-gray (GY 4/1), weathers to thin, fissile flakes; clayey to slightly silty; thinly laminated with laminae 1-2 mm. thick; flecks of black carbonaceous matter. Moderate-brown (5YR 4/4) iron-oxide stain along bedding. Interbedded with five thin, dark-gray (N3) shale beds at base and at 0.45-0.50, 1.1, 1.7, and 2.9 feet above base; contacts sharp. Upper 2 feet of this unit does not have dark-gray shale interbedded and is separated from lower 8.4 feet by a 0.6 foot zone of dark-gray shale with a thin (less than 5 mm.), silty, concretionary pyrite zone. Slightly sideritic concretionary zones, 0.5 foot thick, at 3.0, 4.0-4.5, and 7.5-8.0 feet above base; brittle, tough, dense, conchoidal fracture, weather dark yellowish orange (10YR 6/6). 2 cm.-thick cone-in-cone limestone layer 7.9 feet above base. In upper 2 feet, pyrite nodules are numerous, botryoidal, typically 1-2 cm. and up to 8 cm. long; flattened slightly along bedding, long axis parallels bedding; small pyrite-filled burrows (?) parallel to bedding. Sharp planar contact with underlying unit. Sampled 3 feet above base . . . . .	11.0

Devonian (continued):

Ohio Shale (continued):	Thickness (feet)
9. Shale, brownish-black (SYR 3/1), slightly silty, thickly bedded, in beds 5-6 mm. thick, breaks along bedding with subconchoidal fracture, brittle, tough; 0.4 foot below top is a parting of greenish-gray (SGY 6/1) clay; abundant flecks of unidentifiable black carbonaceous debris, no spores, selenite rosettes along weathered bedding planes; about 1.0 foot below top are two fragments of coalified <u>Callixylon</u> (?) 1.2 feet long and 0.8 foot wide. . . .	6.0
8. Shale, grayish-black (N2) to brownish-black (SYR 2/1), weathers to thin chips, 3-4 cm., light-gray (N7) to medium-light-gray (N6); fissile, thinly laminated, brittle, subconchoidal fracture, slightly silty; where freshest, unit weathers into subround fragments up to 10 cm. across; rare pyrite nodules, 1-2 cm. in diameter; slightly pitted surface on some bedding planes. Abundant black <u>Foerstia</u> , lobate, especially conspicuous in weathered, lighter gray chips. Joints 3 feet apart strike 345° and dip 67° west. Sampled 1 foot above base and at top . . .	12.0
7. Shale, brownish-black (SYR 2/1) and olive-black (SY 2/1), weathers medium light gray (N6) to light gray (N7) with pale-greenish-yellow (10Y 8/2) iron sulfate and dark-yellowish-orange (10YR 6/6) iron-oxide coatings; subconchoidal fracture, brittle, dense where fresh; spores absent to rare. Alternating massive and fissile-weathering beds in 0.5 to 0.8 foot couplets give outcrop a ribbed appearance; thin, brittle chips litter weathered slopes; sulphurous water seeps from near base of section . . . . .	4.2
Total Ohio Shale in single exposure . . . . .	<u>21.5+</u>
Section thickness in units 7 through 38 totals about 383 feet.	

Offset 4.1 miles to southwest on north side of Ohio Highway 32 near its junction with Ohio Highway 73 for description of basal 26.5 feet of section.

6. Covered; poor exposures of this interval along highway from Hackleslin Road to Ohio Highway 73, not measured.

Devonian (continued):

	Thickness (feet)
Ohio Shale (continued):	
5. Covered, with gravel cap to top of exposure; not included in section.	
4. Shale, light-brownish-gray (5YR 6/1) grading upward to greenish-gray (5GY 6/1); <u>Lingula</u> ; fish scales (?); burrows filled with greenish-gray clay. . . . .	3.0
3. Shale, olive-black (5Y 2/1), weathers light-brownish-gray (5YR 6/1), light gray (N7), to yellowish-gray (5Y 8/1); silty; pyrite-cemented layer in basal 2 cm. and some pyrite as flattened discs 2 cm. in diameter along bedding planes; <u>Tasmanites</u> common . . . . .	4.5
Total lower Ohio Shale (incomplete). . . . .	<u>7.5</u>

Olentangy Shale(?):

2. Shale, greenish-gray (5G 6/1) to light-bluish-gray (5B 7/1); silty, non-calcareous; gray streak. 0.1 foot thick, approximately 7 feet above base; at base, pyrite layer, coarsely crystalline, 1-2 cm. thick with knobby, irregular upper surface contains fine, rounded quartz sand. . . . .	7.0
Total Olentangy Shale . . . . .	<u>7</u>

Unconformity.

Silurian (incomplete):

Tymochtee Dolomite (incomplete):

1. Dolomite, yellowish-gray (5Y 7/2), weathers grayish-orange (10YR 7/4); silt-sized grains, uniform; irregular bedding; some pyrite nodules, 2-3 cm.; calcareous at top . . . . .	10.0+
Total Tymochtee Dolomite (incomplete). . . . .	<u>10.0+</u>

Total thickness of lower part of section . . . 24.5

NOTE: Unit 6 (covered interval) is poorly exposed along Ohio Highway 32 between Ohio Highway 73 and the Hackleslin Road. This part of the section in other roadcuts and railroad cuts along Ohio Highway 73 and Portsmouth Road, southeast of the measured composite section, consists of black, fissile shale and greenish-gray shale with large, subrounded calcareous concretions as large as 2 feet in diameter. The thickness of this interval is not known, but Calvert (1968) indicates that the Ohio Shale in this area is nearly 300 feet thick; thus, as much as 70 feet of section may be missing from this description.



### SECTION 3

#### TYPE SECTION OF THREE LICK BED

##### Interstate 64 Section Near Morehead Interchange

Complete section of Sunbury Shale, Bedford Shale, and Ohio Shale exposed in two large roadcuts along Interstate Highway 64; base of section is on south side of highway, 1.35 miles east of Bath-Rowan County line, 1,150 feet FNL x 900 feet FWL Sec. 10-T-71, Rowan County, Kentucky (Farmers quadrangle), at bridge across I-64 at west end of cut. Upper 83 feet of complete section (units 14 - 19) are described from exposures on north side of Interstate Highway 64, 3.20 miles east of Bath-Rowan County line, 1,200 feet FNL x 550 feet FEL Sec. 5-T-72, Rowan County, Kentucky (Farmers quadrangle). Described and measured by Linda J. Provo, Michael D. Lewan, and R. C. Kepferle using hand level and tape, April 28, 1976.

	Thickness (feet)
Mississippian (incomplete):	
Borden Formation (incomplete):	
Henley Bed of Farmers Member (incomplete):	
19. Mudstone, greenish-gray (5GY 6/1), silty; hackly fracture, limonitic stain; grass and vetch cover upper part of exposure. Basal contact sharp. . . . .	1.0+
Sunbury Shale:	
18. Shale, black (N1), very slightly silty, fissile, brittle; weathers medium gray (N6) to yellowish gray (5Y 8/1); fresh pieces have sub conchoidal fracture; pyrite nodules along bedding planes at 4.5 and 5.5 feet above base; no spores, possible vertical and horizontal lens-shaped burrows indicated by lighter zones 2 to 3 mm. wide in uppermost part; lag concentrate at base 5 mm. thick, contains numerous <u>Lingula</u> , a few conodonts, rare spores. Both upper and lower contacts must be excavated to be seen.	
Sampled at base . . . . .	18.2
Total Sunbury Shale. . . . .	<u>18.2</u>
Bedford Shale:	
17. Mudstone, olive-gray (5Y 4/1), slightly calcareous; weathers light olive gray (5Y 6/1); limonite seam along bedding plane 4.4 feet above base . . . . .	14.8

	Thickness (feet)
Mississippian (continued):	
Bedford Shale (continued):	
16. Shale, black (N1), fine, even-textured, little silt; some spores; limonitic coating on sharp upper and lower contacts. . . . .	0.05
15. Mudstone, greenish-gray (5GY 6/1), silty, slightly calcareous; semispheroidal fracture; <u>Lingula</u> at 1 cm. above base. Basal contact sharp. . . . .	<u>0.2</u>
Total Bedford Shale. . . . .	<u>15.05</u>
Devonian:	
Ohio Shale:	
14. Shale, brownish-black (5YR 2/1); fissile, brittle; weathers progressively from medium light gray (N6) surfaces to moderate yellowish-brown (10YR 5/6), dusky yellowish-brown (10YR 2/2) with olive cast, and light brown (5YR 5/6) to dark yellowish-orange (10YR 6/6); morphology of weathered, near-vertical cuts characterized by smooth-weathering faces inter- bedded with splintery fissile-weathering faces to give outcrop a ribbed appearance; typical thick- nesses are 0.1 to 0.3 foot for smooth faces and 0.5 foot for splintery faces; upper 22 feet of unit less well exposed in a steep talus-littered slope with occasional ledges about 0.5 foot thick well exposed; highly altered cone-in-cone limestone layer 1 to 2 cm. thick at 5.2 feet above base; spores small and inconspicuous near top, increase in size and abundance toward base; <u>Lingula</u> found at top. Basal contact with grayish-green shale sharp; offset on this contact to south side of Interstate Highway 64 in Sec. 10-T-71 to west for description of under- lying units. Here flattened, amoebiform phosphate nodules 10 to 15 cm. long were found 31 and 33 feet above base of unit and a trash zone 2 to 3 mm. thick, with <u>Lingula</u> , fish bones, conodonts and small phos- phate pebbles were found in the float on the slope of this unit . . . . .	48.8
Three Lick Bed:	
13. Shale, grayish-green (5GY 4/1), iron-stained; basal contact gradational into black shale over 0.1 foot interval. . . . .	1.5

Devonian (continued):

Thickness  
(feet)

Ohio Shale (continued):

Three Lick Bed (continued):

- |  |             |
|--|-------------|
| 12. Shale, olive-black (5Y 2/1), fissile; like unit 10; pyrite nodules in somewhat persistent zone about 1 foot above base; discontinuous cone-in-cone layer 1.9 feet above base, also observed at same horizon in roadcut to east. Basal contact sharp. . . . .   | 4.2         |
| 11. Shale, greenish-gray (5G 6/1), like unit 9. . . . .  | 0.9         |
| 10. Shale, olive-black (5Y 2/1), fissile; selenite rosettes on bedding planes; spores abundant; basal contact sharp . . . . .  | 2.6         |
| 9. Shale, greenish-gray (5GY 5/1); secondary red (5YR 5/6) stain along bedding; basal 3-5 cm. burrowed, with burrows decreasing in abundance upward; <u>Lingula</u> at base; sharp basal contact. . . . .  | 2.3         |
| Total Three Lick Bed . . . . .   | <u>11.5</u> |
| 8. Shale, medium dark gray (N4) to medium-gray (N5); surface stained yellowish-brown; fissile; numerous spores on some bedding planes; discontinuous cone-in-cone layer attains maximum thickness of 0.2 foot about 5 feet below top of unit; pyrite nodules about 3 mm. thick concentrated along bedding plane about 22 feet above sharp basal contact . . . . .  | 53.8        |
| 7. Shale, brownish-black (5YR 2/1); fissile; like unit 3; homogeneous; at top is a clay-shale seam, 1 cm. thick, which weathers light gray (N7); interlaminated with dark shale in couplets less than 1 mm. thick in 1-cm. interval below seam. . . . .  | 21.6        |
| 6. Interbedded light (60 percent) and dark (40 percent) shale. Light shale is greenish-gray (5GY 4/1) to light olive gray (5Y 6/1), argillaceous, micaceous, poorly fissile in 9 beds ranging from 0.2 to 1.5 feet thick; basal contacts sharp to gradational over 1 cm. Interbedded dark shale is olive black (5Y 2/1), in 8 beds 0.1 to 1.7 feet thick; well-preserved <u>Foerstia</u> common to abundant, some show lobate morphology; basal contacts sharp . . . . . | 8.3         |

Devonian (continued):

Thickness  
(feet)

Ohio Shale (continued):

5. Shale, brownish-black (5YR 2/1), fissile, brittle; weathers blocky and massive in lower two-thirds, less resistant in upper one-third of unit; pyrite occurs along bedding planes; conodonts rare; possible Foerstia? (algae) in upper 0.1 foot of unit; spores in basal 0.1 foot. Sampled at sharp basal contact . . . . . 20.3
4. Shale, interbedded, light (70 percent) and dark (30 percent). Light shale is greenish-gray (5GY 6/1), in beds ranging from 0.2 to 0.5 foot thick; top of uppermost bed is burrowed. Dark shale is brownish-black (5Y 3/1), like underlying unit, in beds 0.1 to 0.3 foot thick . . . . . 9.1
3. Shale, brownish-black (5YR 2/1), brittle, fissile, laminated, with abundant reddish-brown Tasmanites spores and some flakes of chitinous (?) material; pyrite nodules well developed along selected bedding planes; prominent horizon 2.6 feet below top of unit, contains elongate nodules 1 to 3 cm. thick and 3 to 4 cm. wide; another 1-mm.-thick layer occurs at sharp basal contact . . . . . 5.1
2. Shale, light olive-gray (5Y 6/1), greenish-gray (5GY 6/1) to dark greenish-gray (5G 5/1); weathers light gray (N7) to yellowish gray (5Y 8/1), joints stained with limonite; clayey to slightly silty; spores rare; contains interbeds 2 to 3 cm. thick of brownish-black (5YR 2/1) to dark gray (N4) shale with poorly defined contacts at 1.1 feet, 2.7 feet, and 2.9 feet below top. Basal contact is sharp, locally marked by pyritic sandy layer 1 cm. thick, but obscure where pyrite layer is absent. . . . . 3.0
- Total Ohio Shale. . . . . 181.5

Unit may be equivalent of Olentangy Shale.

Unconformity.

Silurian (incomplete):

Crab Orchard Formation (partially exposed):

1. Shale (85 percent) and dolomite (15 percent). Shale is olive-gray (5Y 5/1), clayey, dolomitic, poorly fissile; weathers to light gray (N7) thin flakes 1 to

	Thickness (feet)
Silurian (continued):	
Crab Orchard Formation (continued):	
2 cm. across and 2 mm. thick; in beds about 0.5 foot thick. Dolomite is light olive gray (5Y 6/1); weathers light brown (5YR 5/6) to moderate brown (5YR 4/4); silt-size grains; Chondrites-like burrows are mainly parallel to bedding, but a few are vertical in discontinuous thin beds and fairly continuous thicker beds up to 0.2 foot thick. Remaining part of Crab Orchard Formation not exposed below road level. . . . .	22.0+
Total thickness of section about 238 feet.	

(Note: Reconnaissance hand-level measurement above unit 13 in the western roadcut encountered 50 feet of Ohio Shale to the base of the Bedford Shale; the Bedford was measured as 13.5 feet thick, and the lower 7 feet of the Sunbury Shale was exposed at the top of the cleared roadcut.)

#### SECTION 4

##### Mountain Parkway Section Near Clay City

Nearly complete section of New Albany Shale exposed in two large roadcuts and one quarry along Mountain Parkway in Powell County, Kentucky (Clay City Quadrangle). Upper 54 feet of section are described from cut on east side of Kentucky Highway 1057, south of bridge over Mountain Parkway, 1725 feet FNL x 575 feet FEL Sec. 25-Q-68; the underlying units (1-14) are described from a quarry on the north side of Kentucky Highway 15, 0.1 mile northwest of its junction with Kentucky Highways 11 and 82, and from the large roadcut 0.15 miles farther west; base of section is on north side of Mountain Parkway, 0.25 miles west of overpass at Clay City interchange (Exit 16), 925 feet FSL x 900 feet FWL Sec. 11-Q-67. Described and measured by R. C. Kepferle, Michael D. Lewan, J. B. Maynard, P. E. Potter, and Linda J. Provo using hand level and tape, May 20, 1976.

	Thickness (feet)
Mississippian (incomplete):	
Nancy Member of Borden Formation (incomplete):	
23. Covered, to top of ridge overgrown by grass and small evergreen trees; not measured; contact with underlying unit is not exposed but is mapped at elevation 720+ feet (Simmons, 1967) and is believed to be near top of exposure, below.	

	Thickness (feet)
Devonian (incomplete):	
New Albany Shale:	
22. Shale, dark gray (N3), slightly silty, fissile; basal contact marked by underlying phosphate nodules. . . .	4.7+
21. Shale, dark gray (N3), slightly silty, uniform, fissile; elongate, flattened phosphate nodules as much as 0.3 foot long and 0.1 foot thick occur randomly along bedding planes; iridescent limonitic coating on bedding planes; fish scales and unidentifiable parts, rare; spore <u>Tasmanites</u> , common; contact with underlying cone-in-cone limestone layer sharp. Sampled at top of unit. . . . .	24.0
20. Shale, brownish-black (5YR 2/1), silty, fissile; yellowish-gray (5YR 7/2) powdery, weathered coating on bedding planes; at top is continuous cone-in-cone limestone layer, 0.1 foot-thick, heavily stained with limonite; spores abundant. Contact with underlying unit sharp. . . . .	19.2
Three Lick Bed:	
19. Mudstone, medium-light gray (N6), silty; poorly laminated, hackly fracture; selenite crystals and limonitic stain on weathered surfaces; unit sampled at westernmost cut. Basal contact sharp. . . . .	0.7
18. Shale, dark gray (N3) to medium-dark gray (N4), well laminated, with laminae about 1 mm. thick; few <u>Tasmanites</u> ; selenite rosettes and limonitic stain along bedding planes. Basal contact sharp. . . . .	2.7
17. Mudstone, medium-light gray (N6), like unit 18; sampled at westernmost cut. Basal contact sharp. . . . .	0.5
16. Shale, dark-gray (N3), like unit 17 . . . . .	1.7
15. Mudstone, medium-light gray (N6); like unit 18; base and top are gradational; sampled in westernmost cut. The alternation of gray mudstone and dark-gray shale imparts a ribbed appearance to the outcrops that includes units 18 to 14. Offset on this contact to quarry on north side of Kentucky Highway 15, 2.1 miles to northwest, in Sec. 11-Q-67 for description of the underlying unit . . . . .	0.6
Total Three Lick Bed . . . . .	<u>6.2</u>

Devonian (continued):

Thickness  
 (feet)

New Albany Shale (continued):

14. Shale, dark gray (N3), fissile, massive, uniform; interbedded with as many as six fairly continuous medium-gray (N5) to medium-dark-gray (N4) cone-in-cone limestone layers which are locally pyritic and are commonly less than 0.1 foot thick at base and top of unit and at 2.1, 7.3, 8.7, 12.2, 13.0, 14.3, 23.1, and 24.2 feet above base locally in this and adjacent exposure to west; cone-in-cone beds weather to limonite-stained light brown (5YR 5/6); lowest, highest, and bed 7.2 feet above base were sampled. Offset along contact to exposure 0.15 miles to west . 26.9
13. Shale, dark-gray (N3) to brownish-black (5YR 2/1); silty, well-laminated, with laminae 1-2 mm. thick; even fracture, tough; rare Tasmanites; poorly formed selenite rosettes and irregular masses of selenite common common along bedding planes and fractures, which are also stained with limonite and sulfate. . . 17.3
12. Covered at road; probably similar to underlying unit 10; section offset across Kentucky Highway 15 to south . . . . . 2.4
11. Shale, brownish-black (5YR 2/1), silty; more fissile than underlying units; red-brown Tasmanites spores abundant; Foerstia prominent in weathered zone 4.1 feet above base (sampled); limonite and sulfate stain on bedding and joint planes . . . . . 12.2
10. Covered; probably similar to unit 8; slope littered with thin, medium gray shale chips. . . . . 1.7
9. Shale, grayish-black (N2), fine silt; fissile; weathers to splintery fragments; pyritic; 3.6 feet below top of unit is a highly weathered zone 0.4 foot thick containing abundant spores and iron-sulfide nodules which have finely crystalline, rounded bases and which mushroom upward into coarser octahedral crystals, with bedding draped around crystals (this zone is also identifiable in the quarry exposure to the east); limonite and sulfate stain on joint faces; sampled 5.2 feet below top of unit. . . . . 10.0

Devonian (continued):

Thickness  
 (feet)

New Albany Shale (continued):

8. Light and dark shale interbedded in subequal amounts in about 20 couplets. Light shale is olive gray (5Y 4/1) to greenish gray (5GY 6/1) and medium gray (N5) in beds commonly 0.1 foot thick and as much as 1.0 foot thick; burrows (?) common to rare along bedding planes, some ramose and straight, others fainter and meandering; coaly material in one bed near middle of unit. Dark shale is brownish black (5YR 2/1), dark gray (N3) to grayish black (N2) in beds ranging in thickness from 0.1 to 1.5 feet; pyritic; fossils include sparse Tasmanites spores and conodonts, rare Lingula and, near top, Foerstia (?) and Zoophycos-like burrows. Boundaries between beds sharp to gradational over 1 to 2 cm. . . . . 10.4
7. Shale, grayish-black (N2), fissile, like unit 4. . . . . 1.3
6. Covered, at first major bench above base; slope littered with light gray shale chips . . . . . 2.0
5. Shale, grayish-black (N2), fissile, brittle, with subconchoidal fracture where fresh; weathers to light-gray (N7) chips which litter slopes; pyrite in irregular concentrations along bedding planes; some Tasmanites and Lingula; heavily stained with limonite and sulfate; basal contact gradational over 0.1 foot . . . . . 4.0
4. Dolomudstone, olive gray (5Y 4/1), weathers to rounded prisms less than 1 cm. on a side; clayey; lower contact sharp. . . . . 0.9
3. Interbedded shale and dolomudstone in descending order: shale, 1.9 feet; dolomite, 1.0 foot; shale, 1.1 feet; dolomite, 0.3 foot; shale, 0.2 foot; dolomite, 0.8 foot; shale, 0.3 foot (basal shale sampled). Shale is dark gray (N3), slightly silty, fissile, brittle, well-laminated, with laminae about 2 mm. thick; abundant Tasmanites spores; burrows (?) are gently curved, 0.5 to 1 cm. wide, locally pyritic, common on bedding planes. Dolosiltstone is olive gray (5Y 4/1), bioturbated. Basal contact is gradational . . . . . 5.6

Devonian (continued):

Thickness  
 (feet)

New Albany Shale (continued):

2. Shale, olive gray (5Y 4/1), silty, dolomitic near base; weathers to very light gray (N8), poorly fissile chips less than 1 cm. across; ribbed weathering pattern well-developed in upper 3 feet of unit in couplets 0.3 to 0.4 foot thick; blocky weathering zone occurs 2.5 feet above base; Tasmanites common; sampled 2.1 feet above base. Basal contact is sharp, unconformable, irregular, with local relief of about 0.1 foot. . . . . 7.8
- Total New Albany Shale (see note). . . . . 156.6

Unconformity:

Boyle Dolomite (incomplete):

1. Dolomite, medium-light-gray (N6), silt-sized grains; weathers to grayish-orange (10YR 7/4); dense, with some wavy bedding and stylolites; chert nodules, medium-gray (N5), irregular to amoebiform, as much as 0.3 foot thick and 2 feet long; discontinuous clay parting 1.5 feet below top; calcite, pyrite, and sphalerite occur as irregular blebs in upper 0.5 foot, but appear to be unrelated to concentration of burrows (?) in same interval and which are parallel to bedding and a few centimeters wide; crinoids and other fossils weather out forming a pitted, irregular surface, suggesting that this unit may be a dolomitized limestone. Unit appears as single massive bed; remaining Boyle not exposed at road level in this section . . . . . 4.4
- Total thickness of section is about. . . . . 161

(Note: In the westernmost cut the inclusive interval between the lowest and highest greenish-gray mudstone beds (correlative with units 15 through 19 in the quarry part of the section) is 5.8 feet. Above this interval, a thickness of 21 feet of black shale is exposed on the steep face of the cut, and the uppermost 25 feet are covered. The uppermost 4 feet of the ridge is capped by the Nancy Member of the Borden Formation. Thus, the total thickness of the New Albany Shale at the westernmost section is about 152 feet.)

## SECTION 5

### Berea, Kentucky, Section

Nearly complete section of New Albany Shale exposed in series of cuts on east side of Interstate Highway 75 at and south of exchange and crossing of Kentucky Highway 21 west of Berea, Madison County, Kentucky. Top of section is south of overpass, 575 feet FNL and 600 feet FWL of Sec. 7-M-63; base of section is along entrance ramp to the northbound lanes of Interstate Highway 75 (Berea quadrangle). Section measured, described, and sampled, and its radioactivity profile measured using Jacob's staff, tape, Abney level, and scintillometer by R. C. Kepferle and Paul Edwin Potter, July 9, 1976.

	Thickness (feet)
Quaternary (?)	
15. Soil, olive-gray (5Y 4/1) to yellowish-gray (5Y 8/1), containing, near base, quartzite pebbles, siliceous geodes, and phosphatic nodules derived from nearby and underlying bedrock units; weathers to grassy flat. Erosional contact. . . . .	5+
Devonian:	
New Albany Shale (incomplete):	
14. Shale, brownish-black (5YR 2/1), weathers light gray (N7), with some iron oxide and sulfide stain on fractures and bedding planes along with rosettes and prisms of selenite 3 to 5 mm. long; silt in discontinuous laminae 1 to 2 grains thick; pyrite in discoidal concretions and disseminated grains; phosphate in nodules which are round to amoebiform, 2 to 3 cm. thick, elongate, some more than 13 cm. across, brownish-gray (5YR 4/1) and brownish-black (5YR 2/1), weather yellowish-gray (5Y 8/1) on surface, with earthy luster and rough fracture; fossils include <u>Tasmanites</u> spores and a vitrain layer 3 mm. thick 5 feet above base. Top at or near contact with grayish-green shale of basal Borden Formation seen in outcrop less than 1 mile to the west. Basal contact placed at lowest phosphate nodule. . . . .	9
13. Shale, brownish-black (5YR 2/1) to grayish-black (N2), like unit above, except contains no phosphate nodules; 8 feet above base is zone of pyrite concretions 0.1 foot in diameter and 0.5 cm. thick, concentrated along bedding planes; shale weathers to fissile, brittle flakes and plates as much as 0.4 foot in diameter; <u>Tasmanites</u> abundant; possible fish scale, 1 mm. across,	

Devonian (continued):

Thickness  
 (feet)

New Albany Shale (continued):

near top of unit; silt laminae increase in abundance downward; tough and dense, with subconchoidal fracture where fresh. Sharp basal contact. . . . . 18

Three Lick Bed:

12. Shale, greenish-gray (5GY 5/1-4/1), weathers yellowish-gray (5Y 8/1), clayey, subconchoidal fracture on joints and partings coated with limonite and sulfate stain. Sharp contact with underlying unit. . . . . 0.8

11. Shale, black (N1) to grayish-black (N2) and brownish-black (5YR 2/1); weathers light gray (N7), with iron oxide and sulfate stain; silt laminae 1 to 2 grains thick, commonly about 5 mm. to 1 cm. apart; brittle flakes litter outcrop; burrowed in upper 0.1 foot, burrows filled with greenish shale from overlying unit?; discontinuous cone-in-cone limestone layer, dark-gray (N5), 0.1 thick, about 0.6 below top (sampled); basal contact sharp. . . . . 1.2

10. Shale, greenish-gray (5GY 5/1 to 4/1) like unit 12; basal contact sharp . . . . . 0.4

9. Shale, brownish-black (5YR 2/1) like unit 11; fish scale(?) 0.3 above base; Tasmanites sparse; upper 0.1 burrowed; pyrite up to 2 mm. in scattered blebs; basal contact sharp . . . . . 0.9

8. Shale, greenish-gray (5GY 5/1) like unit 12; sharp contact with underlying unit. Offset north along contact to first cut south of interchange; and in borrow pit east of cut. . . . . 0.2

Total Three Lick Bed . . . . . 3.5

7. Shale, black (N1), grayish-black (N2), and brownish-black (5YR 2/1); slightly silty; some silt laminae 1 to 2 grains thick about 5 mm. apart; burrowed in upper 0.2 feet; burrows are gently curving, burrow-fill is medium dark gray (N4); as much as 0.5 cm. wide along bedding planes; Tasmanites sparse to abundant; some scattered black organic shreds; pyritic; slightly more resistant-weathering rib at about 20 feet above base (near base of cut); in upper 15 feet is rhythmic alternation of massive- and

Devonian (continued):

Thickness  
 (feet)

New Albany Shale (continued):

<p>fissile-weathering shale in sets 0.5 foot thick that impart ribbed appearance to otherwise littered slope. Poorly preserved <u>Foerstia</u> in 2.5 feet thick zone 8.9 feet above base of unit; weathered chips typically have slight depressions on surfaces, where <u>Foerstia</u> have weathered out. All but lower 10 feet described up slope from middle light pole of north cut; basal 10' described from borrow pit to east . . . . .</p>	37
<p>6. Interbedded light (60 percent) and dark shale. Light shale is greenish-gray (5Y 6/1) in 7 beds decreasing downward in thickness from 2.4 to 0.1 feet; thickest gray shale contains 4 thin brown-shale streaks. Dark shale is brownish-black (5YR 2/1) to dusky brown (5YR 2/2); silty in thin laminae in 6 beds 1.3 to 0.1 feet thick; lowest dark shale burrowed (dug this section out) . . . . .</p>	5.6
<p>5. Shale, black (0.1+ foot), and covered . . . . .          Offset to north-bound entrance ramp to I-75</p>	16
<p>4. Dolomudstone, greenish-gray (5G 6/1), weathers to yellowish-gray (5Y 8/1) prisms with spheroidal sides. Basal contact sharp. (Top covered in grass on west side; may be black shale recoverable across to west). . . . .</p>	2.7+
<p>3. Organic dolomitic mudstone, olive-black (5Y 2/1), weathers yellowish-gray (5Y 8/1); laminated; base marked by 0.05-thick rippled(?) sandy layer. Basal contact sharp . . . . .</p>	1.7
<p>2. Dolomitic mudstone, laminated, olive-black (5Y 2/1); base sharp, irregular, relief of about 0.1 foot; weathers yellowish-gray (5Y 8/1). . . . .</p>	1.2
<p>Total New Albany Shale . . . . .</p>	<u>94.7</u>

Unconformity.

Boyle Dolomite (incomplete):

1. Dolomitic limestone, dark gray (N3), olive gray (5Y 4/1), to light-olive-gray (5Y 6/1); weathers yellowish-brown (5YR 5/4) to dark yellowish-orange (10YR 6/6); locally conglomeratic, with lighter olive pebbles 1 to 6 cm. long in a darker matrix; scattered white calcite-filled pockets and massive chert in

Devonian (continued):	Thickness (feet)
Boyle Dolomite (continued):	
some beds; bed thickness 0.9 to 2.5 feet, accentuated by weathering along stylolitic bedding planes. Base not exposed . . . . .	9.2+
Total thickness of section, approximate. . . .	<u>109</u>

(Note: The slopes of the Interstate cuts lie at about 30° and are mainly mantled by a thin talus which can be removed by some trenching with mattock or shovel. The uppermost part of the New Albany Shale is well exposed about 1 mile west of the southern cut. There the shale is overlain by about 0.6 foot of brownish-gray to olive-gray shale, about 0.05 foot of black shale and then by the greenish-gray shale of the basal Borden.)

## SECTION 6

### Big Clifty Creek Section

Complete section of Chattanooga Shale exposed in small unnamed tributary to Big Clifty Creek and along Ringgold Road, 4.1 miles northwest of its junction with Old Kentucky Highway 80 at West Somerset, Pulaski County, Kentucky (Delmer quadrangle). Base of section is in unnamed tributary, 2,850 feet FSL x 2,400 feet FEL of Sec. 19-H-58; top of Chattanooga Shale is along unpaved road, 3,000 feet FSL x 2,425 feet FWL of Sec. 19-H-58. Section measured, described, and sampled using Jacob's staff, Abney level, and tape and its radioactivity profile measured using scintillation counter by R. C. Kepferle, P. E. Potter, and Linda J. Provo, August 3, 1976.

Mississippian (incomplete):	Thickness (feet)
Borden Formation (incomplete):	
Nancy Member (incomplete):	
7. Shale, greenish-gray (5G 5/1), weathers light olive gray (5Y 7/1) to greenish-gray (5G 7/1); silty; rounded phosphate nodules along bedding planes approximately 1.4 and 2.8 feet above base, with glauconite around nodules . . . . .	15+
Total Nancy Member (incomplete) . . . . .	<u>15+</u>

	Thickness (feet)
Devonian (incomplete):	
Chattanooga Shale:	
6. Shale, brownish-black (5YR 2/1) to olive-black (5Y 2/1), weathers to light gray (N7) plates and chips; bedding planes and joints coated with sulfates of iron; <u>Tasmanites</u> common; abundant olive-gray (5Y 4/1) phosphate nodules, weather gradationally to chalky white, earthy luster, ovoid and elongate or amoebiform, typically 3-5 cm. thick and up to 1 foot long, somewhat flattened along bedding planes, bedding contorted over nodules; base of unit is at lowest occurrence of phosphate nodules; silica "dike", 2 cm. wide, vertical, geodiform, extends 15 feet laterally in ditch along unpaved road and 3 feet vertically into overlying unit. Contact with overlying Nancy Member is abrupt; a 0.2-foot-thick zone of phosphate nodules (sampled) in glauconite-stained mudstone (possibly equivalent to Maury Formation) occurs at top of this unit. . . . .	7.0
5. Shale, brownish-black (5YR 2/1), like unit 3. . . . .	7.0
Three Lick Bed:	
4. Mudstone and shale, interbedded. Mudstone is olive gray (5Y 4/1), weathers moderate brown (5YR 4/4); clayey, pyritic; in three beds, less than 0.1 foot thick, occurring between 32.7 and 35 feet above base of section. Shale is brownish-black (5YR 2/1), like unit 3, with <u>Tasmanites</u> and sparse <u>Lingula</u> ; burrowed immediately below mudstone beds; burrows curved, smooth-sided, up to 1 cm. wide, filled with light-brownish-gray clay (5YR 6/1), decrease in abundance upward to gray shale. . . . .	<u>2.3</u>
Total Three Lick Bed. . . . .	<u>2.3</u>
3. Shale, olive-black (5Y 2/1), weathers to medium-light-gray (N6) fissile chips and plates; pyrite in burrows in basal 0.5 foot and as stellate nodes which disrupt bedding and stand in relief on bedding planes, abundant pyrite as cubes and accretions at 24 to 26 feet above base with abundant lanceolate fish scales(?); <u>Lingula</u> common to abundant to 3.5 feet above base (oriented sample at 3.0 feet above base), long axes oriented at 206°, 283°, 291°, 300°, 301°, 304°, and 323°; thin clay shale seams, yellowish-brown (10YR 5/2), weathering yellowish-gray (5Y 8/1) and slightly recessed, less than 0.1 foot thick, occur 5.3, 15.8,	

Devonian (continued):

Thickness  
 (feet)

Chattanooga Shale (continued):

16.7, and 17.7 feet above base; Tasmanites rare to abundant; rounded, medium-sized grains (20-30%) occur near base of unit; weathered outcrop has ribbed appearance due to alternating resistant and nonresistant beds in couplets 0.3 foot thick. Off-set along bedding plane 5 feet below top to tributary to east. Basal contact sharp, paraconformable. 31.7

2. Sandstone, Duffin layer, olive-black (5Y 2/1) to brownish-black (wet, 5YR 2/1), weathers yellowish-gray (5Y 7/2) to moderate yellowish-brown (10YR 5/4); sand grains medium-sized, well-rounded, frosted; phosphatic, dolomitic; basal 0.2 foot contains phosphate pebbles 2-3 cm. wide which stand out in relief; pyrite as nodules 2 cm. wide near top; conodonts and fish(?) remains observed. Contact with underlying unit, disconformable (sampled) . . . . . 0.9
- Total Chattanooga Shale<sup>1/</sup> . . . . . 48.9

Unconformity.

Boyle Limestone (incomplete):

1. Dolomite, olive-gray (wet, 5Y 4/1) weathers medium light gray (N6) to light gray (N7), limy, medium-grained, pyritic, few glauconite grains; fluted- and rounded-weathering beds 0.6-0.7 foot thick; 1.3 feet below top is 0.5-foot-thick bed of chert, mottled yellowish-gray (5Y 7/2) and olive-gray (5Y 4/1); weathers moderate brown (5Y 4/4) to dusky red (5R 3/4), iron oxide stain; dolomite contains solitary corals and brachiopods, locally calcite-filled. Base covered. . . 2.6
- Total Boyle Limestone (incomplete). . . . . 2.6+
- Total thickness of section, approximate . . . . 67

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<sup>1/</sup> NOTE: Compares with 47.4 feet of Chattanooga Shale measured by Hass (1956, p. 27) at the same locality (Conant and Swanson, 1961, loc. 6).

# SECTION 7

## Creelsboro Section

Complete section of Chattanooga Shale along east side of Kentucky Highway 379 and in gulley along old road east of Highway 379, 2.9 miles west of Creelsboro, Russell County, Kentucky (Creelsboro quadrangle). Base of measured section is 1,900 feet FNL x 2,225 FEL in Carter coordinate, Sec. 15-E-52. Section measured and described using Jacob's staff, Abney level, and tape and its radioactivity profile measured using scintillation counter by R. C. Kepferle, P. E. Potter, and Linda J. Provo, August 3, 1976.

Mississippian (incomplete):	Thickness (feet)
Ft. Payne Formation (incomplete):	
12. Mudstone, greenish-gray (5GY 6/1), silty, glauconitic	5.0+
11. Mudstone, olive-gray (5Y 4/1), shaly. . . . .	0.2
Total Ft. Payne Formation (incomplete). . . . .	<u>5.2+</u>

### Devonian:

#### Chattanooga Shale:

10. Shale, brownish-black (5YR 2/1), petroliferous odor, abundant pyrite; contact with overlying Ft. Payne Formation is sharp and conformable. . . . .	0.4
9. Phosphatic nodules, concentrated in layer . . . . .	0.1
8. Shale, brownish-black (5YR 2/1), slightly silty, slightly pyritic, weathers to medium-light-gray fissile flakes and chips; phosphate nodules occur 4.4 feet above base and extend to top with long axes oriented at 183°, 188°, 190°, 193°, 200°, 207°, and 215°. . . . .	15.9
7. Shale and mudstone. Shale is brownish-black (5YR 2/1), like unit 6, and burrowed. Mudstone occurs as three very thin seams, less than 1 cm. thick; unit possibly equivalent to Three Lick Bed. . . . .	1.7

Devonian (continued):

Thickness  
 (feet)

Chattanooga Shale (continued):

6. Shale, brownish-black (5YR 2/1), weathers to medium-light-gray (N6) fissile flakes and chips; slightly silty with a few silt laminae one or two grains thick; slightly pyritic; Tasmanites common, and show upward increase in abundance; unit forms distinct, massive face; at 4.0 feet above base is a light-brown (5YR 5/6) clay parting 1 cm. thick; discontinuous dolomitic and pyritic layer, 0.1 foot thick, occurs 8.4 feet above base of unit. . . . . 13.1
5. Mudstone (70 percent) and shale (30 percent). Mudstone is brownish black (wet, 5YR 2/1) to medium dark gray (dry, N4), occasionally mottled with burrows parallel to bedding; beds range from 0.1 to 0.8 foot in thickness. Shale is brownish black (5YR 2/1), pyritic; contains Tasmanites, a few clay partings, and burrows; upper 0.2 foot is a "varved" bed of black shale and silt laminae 1 mm. thick. . . . . 4.2
4. Shale, black (wet, N1) to brownish-black (5YR 2/1), weathers to medium-gray (N5) to light gray (N7) thin, fissile flakes and plates; strong petroliferous odor from freshly broken surface; pyrite in stellate nodes; abundant conodonts on bedding plane near top of unit; burrowed along bedding planes near base; discontinuous conglomerate 0.2 above base, 0.1 foot thick, contains phosphate pebbles and bone fragments in sandy matrix. Basal contact sharp . . . . . 3.5
- Total Chattanooga Shale . . . . . 38.9

Unconformity.

Kiddville (?) Bed:

3. Chert-pebble conglomerate in medium-grained, poorly sorted, well-rounded, sand matrix; iron-stained, discontinuous . . . . . 0-0.5

Boyle (?) Limestone:

2. Limestone residuum of silt and clay weathered and oxidized to moderate brown (5YR 4/4) to dark yellowish-brown (10YR 4/2); identifiable by chert content and position; chert occurs in three fairly continuous layers of olive-gray (5Y 4/1) to yellowish-gray (5Y 8/1), locally banded and mottled irregular nodules, which range in thickness from 0.2 foot to over 1.0 foot. . . . . 2-3.0
- Total Boyle (?) Limestone residuum. . . . . 2-3.0

	Thickness (feet)
Unconformity.	
Ordovician (incomplete):	
Cumberland Formation (incomplete):	
1. Limestone, olive-gray (wet, 5Y 4/1), light-gray (dry, N7), weathers to light olive gray (5Y 7/1) to yellowish-gray (5Y 8/1); silt-sized grains; sparse glauconite; uniform, laminated; semi-conchoidal fracture; unfossiliferous except as burrows indicated by slight mottling; upper contact abrupt and uneven with relief as great as 1 foot in 10-foot-wide exposure . . . . .	3.0+
Total Cumberland Formation (incomplete) . . .	3.0+
Total section, about. . . . .	50

Note: Complete section occurs along highway at 1900 feet FNL x 2,225 feet FEL of Sec. 15-E-52 and extends to gulley beside highway; top is not clearly exposed in gulley, but is well-defined. Orientations of phosphate nodules were taken from gulley exposure. Description of units 7 through 12 was made along main highway cut, a few hundred feet north, where exposures were better.

## SECTION 8

### Pleasant Grove Section

Complete section of Chattanooga Shale exposed in cut on north side of parking lot at Pleasant Grove Recreation Area of Dale Hollow Lake, 3.75 miles northeast of Tennessee Highway 53 bridge over Obey River at Celina, Clay County, Tennessee (Dale Hollow Dam quadrangle). Base of section is located 1,675 feet FNL x 150 feet FWL in Carter coordinate, Sec. 19-A-49E. Section measured and described using Jacob's staff, Abney level, and tape and its radioactivity profile measured using scintillation counter by R. C. Kepferle, P. E. Potter, and Linda J. Provo, August 4, 1976.

Mississippian (incomplete):	Thickness (feet)
Ft. Payne Formation (incomplete):	
11. Limestone (grainstone), medium-light-gray (N6), weathers to yellowish-gray (5Y 8/1); coarse-grained, crinoidal, stylolitic bedding, dolomitic and glauconitic in basal 0.3 foot; silicified in discontinuous bands of chert up to 0.3 foot thick and less than 1.0 foot apart; chert is medium light	

Mississippian (continued):

Thickness  
(feet)

Ft. Payne Formation (continued):

gray (N6), weathers light gray (N7); basal contact erosional and disconformable. Overlying this 9-foot-thick unit are a mudstone bank (10 feet), crinoidal packstone (2 feet), and greenish-gray shale interbedded with thin dolomitic and cherty wackestones (16 feet) . . . . .	37.0+
Total Ft. Payne Formation (incomplete). . . . .	<u>37+</u>

Maury Shale:

10. Phosphatic nodules in matrix of yellowish-gray (5Y 7/2) shale. Nodules are spherical to elongate and oriented at 117°, 121°, 124°, 134°, 139°, 146°, 170°, 203°, and 218°. . . . .	0.6
Total Maury Shale . . . . .	<u>0.6</u>

Devonian (?):

Chattanooga Shale:

9. Shale, grayish-black (N2), weathers dark greenish-gray (5GY 4/1); occasional silt laminae; phosphate pebbles abundant in upper 0.2 foot; slightly pyritic with fairly continuous zone of 1-3 cm. pyrite nodules about 0.3 foot above base and scattered throughout; translucent, white conodonts common; sparse <u>Lingula</u> about 1.0 foot below top. . . . .	5.3
8. Shale, like unit 9. In this unit occur three burrowed zones, 2 cm. thick, at base, 0.1 foot above, and at top; burrows are 2-3 mm. wide, with dusky yellow (5Y 6/4) fill, and some vertical burrows extend downward into underlying black shale as much as 0.1 foot; basal burrowed zone characterized by greater abundance of and smaller size of burrows; probable correlative of Three Lick Bed . . . . .	0.7
7. Shale, grayish-black (N2), like unit 9, with silty blebs (burrows?); base is marked by lowest occurrence of phosphate nodules. . . . .	4.4
6. Shale, grayish-black (N2), like unit 9, several thin pyrite seams and silt laminae; wood fragments oriented at 72° and 104°, 3.8 feet above base; 2.8 feet above base is a zone of elongate, 1-2 mm. tetragonal(?) crystals and crystal casts (sampled). . . . .	5.1

Devonian (continued):	Thickness (feet)
Chattanooga Shale (continued):	
5. Burrowed zone, with burrows not well-defined. . . . .	0.4
4. Shale, black (N1), dense. . . . .	0.7
3. Shale, olive-black (5Y 2/1) . . . . .	<u>0.4</u>
Total Chattanooga Shale . . . . .	<u>17.0</u>

Unconformity.

Boyle (?) Dolomite (incomplete):	
2. Limestone layer, pyritic, glauconitic . . . . .	0.1
1. Dolomite, olive-gray (5Y 5/1), weathers light brown (5YR 5/6); cherty; silicified brachiopods stand out in relief . . . . .	<u>0.7+</u>
Total Boyle (?) Dolomite (incomplete) . . . . .	<u>0.7+</u>
Total section, about . . . . .	<u>55</u>

This section is near section 16 of Conant and Swanson (1961, pl. 1), where 16.2 feet of shale are assigned to the Cassaway Member (Conant and Swanson, 1961, pl. 12). Thus, unit 3 above may correlate with the Dowelltown Member to the south.

SECTION 9

Flat Gap Road Section

Incomplete section of Chattanooga Shale and Grainger Formation exposed for 0.55 mile in roadcuts and creek beds along northeastern side of Tennessee Highway 31 (Flat Gap Road); top of Chattanooga Shale is located 4.25 miles north of junction of U.S. Highway 11W and Tennessee Highway 31 at Mooresburg, Hawkins County, Tennessee (Lee Valley quadrangle), 2,475 feet FSL x 2,875 feet FWL in Carter Coordinate, Sec. 24-1S-76E. Section measured, described, and sampled, and its radioactivity profile measured using Jacob's staff, Abney level, tape, compass, and scintillation counter by R. C. Kepferle, P. E. Potter, and Linda J. Provo, August 5, 1976.

Mississippian (incomplete):

Thickness  
 (feet)

Grainger Formation (incomplete):

Basal siltstone member (incomplete):

27. Interbedded siltstone (90 percent) and shale (10 percent). Siltstone is olive-gray (5Y 5/1), weathers dark yellowish-orange (10YR 6/6), uniform micaceous, noncalcareous; beds with sharp, planar bases; bed thickness increases upward from 0.1-0.3 foot at base to as much as 1.4 feet at 6 feet above base; possible Bouma sequences  $T_{abc}$  in some beds; lumpy sole marks and low-relief flute marks rare, oriented at  $207^\circ$  with blunt end toward northeast. Shale is olive-gray (5Y 4/1), silty, with grain size fining upward, poorly laminated, with thin elongate and flattened siderite nodules in fossiliferous beds commonly less than 0.3 foot thick. Basal parts of shale beds may represent  $T_e$  in Bouma (1962) sequence. Strike,  $85^\circ$ ; dip,  $26^\circ S$  . . . . .

10+

Total Grainger Formation (incomplete) . . . . 10+

Devonian (incomplete):

Chattanooga Shale (incomplete):

26. Shale (90 percent) and siltstone (10 percent). Shale is medium dark gray (N4) with olive-gray cast, weathers medium light gray (N6) to light gray (N7); thinly laminated, noncalcareous; 50 feet below top shale is medium dark gray (dry, N4) to olive-black (wet, 5Y 2/1), pyritic, weathers subconchoidally and to small splinter; rare, noncalcareous nodules with limonitic crust, 2 feet long and 0.2 foot thick, along some bedding planes; bedding cut by joints and fractures.

Siltstone is olive-gray (wet, 5Y 4/1) and medium light gray (dry, N6), weathers light gray (N7) with moderate yellowish-brown (10YR 5/4) limonitic stain, micaceous, pyritic, with fine specks of disseminated organic (?) debris; laminated, with  $T_{ab}$  Bouma (1962) sequences in beds commonly less than 0.2 foot thick, slightly graded; in upper part of unit sole marks include flute casts at  $244^\circ$  with blunt end toward east; siltstone beds increase in abundance upward in unit, with a bundle of siltstone beds less than 2 feet thick occurring 3 to 5 feet below top of unit. Discontinuous clay ironstone nodules, 2-3 cm. thick occur throughout unit. Beds strike  $68^\circ$ , dip  $26^\circ S$ . . . . . 90

Devonian (continued):

Thickness  
 (feet)

Chattanooga Shale (continued):

25. Covered interval between end of highway cut and creek bed to northeast. . . . . 40
24. Shale, brownish-black (dry, 5YR 2/1) to black (wet, N1), weathers light gray (N7), slightly silty, pyritic, rare Tasmanites, and fish scale (?) fragments; joints coated with moderate reddish-brown (10R 4/6) limonitic material; exposed in stream east of culvert, where beds strike 95°, dip 30°S. Sampled about 1 foot below top. . . . . 6
23. Covered interval along road to north, probably shale like unit 24. . . . . 20
22. Shale, like unit 24, highly weathered exposure in farm lane east of Tennessee Highway 33 about 50 feet from road. . . . . 5+
21. Siltstone, very light olive-gray (5Y 7/1), muddy; limonite-stained joints; sharp contact with overlying shale; strike 78°; dip 29°S . . . . . 3
20. Covered . . . . . 35
19. Siltstone, light olive-gray (5Y 6/1), weathers yellowish-gray (5Y 7/1), noncalcareous, coarse-silt-sized grains, limonitic stain on weathered surfaces; bedding irregular and disrupted, suggesting burrowing; dark, clayey laminae are olive-gray (5Y 4/1); bedding thins and grain-size fines toward base of exposure, grading into siltstone interbedded with silty shale containing discontinuous clay ironstone nodules. Exposure, opposite Gordon home, weathers to elongate plates and chips with irregular, lumpy surfaces. . . . . 25
18. Covered; projected along road from base of overlying unit. . . . . 105
17. Siltstone, medium light gray (N6) to medium dark gray (N4) when dry, olive-gray (5Y 4/1) when wet; pyritic, burrowed, somewhat laminated, parting surfaces commonly less than 0.1 foot thick; steeply dipping fault plane bounds lower limit of unit. . . . 8

Fault.

Devonian (continued):

Thickness  
 (feet)

Chattanooga Shale (continued):

16. Siltstone, like unit 17, in a thinning-upward cycle in which beds in upper half part along muddy layers less than 1 cm. thick; bedding surfaces burrowed, with curly, meandering trace fossils (Scalarituba missouriensis); lower half of unit is massive-weathering with slickensided surfaces. Wood fragment, 10 cm. long, oriented at 282°. Strike 85°, dip 31°S. . . . . 13±2
15. Siltstone, like unit 17, in a thinning upward sequence in which basal 4 feet are massive with slickensided face and upper 3 feet are shaly-weathering owing to laminae of darker, argillaceous material; burrowed. . . . . 7
14. Siltstone, light gray (N7) with interlaminated medium dark gray (N4) clayey silt, ripple-cross-laminated in massive, blocky-weathering beds; sole marks; burrows near tops of beds, medium-dark gray (N4) to olive-black (5Y 2/1) argillaceous and carbonaceous partings about 0.3 foot thick. Basal 10-12 feet is more carbonaceous and weathers to thin plates and fissile chips. As a whole, unit 14 is a thickening upward sequence interrupted by two or three platy-weathering zones less than a foot thick. . . . . 45
13. Deformed zone. Shale and siltstone contorted; likely that disturbance is associated with shalier portions of this zone . . . . . 20
12. Siltstone (80 percent) and shale (20 percent). Siltstone is medium gray (N5) to light olive-gray (5Y 6/1), limonitic weathering stain, micaceous along bedding planes; planar lamination common, ripple lamination less common, Tab and possible Tabc sequences of Bouma (1962); maximum bed thickness 2 feet. Shale is medium gray (N5) to olive-gray (5Y 4/1); shaly-weathering ledge, 1.2 feet thick at base, vitrain layer at top. Unit 12 is a sequence in which beds thicken toward middle of unit from lower and upper boundaries; two thinning upward cycles each about 10 feet thick occur in basal 20 feet. . . . . 50

Devonian (continued):

Thickness  
 (feet)

Chattanooga Shale (continued):

11. Shale and siltstone interlaminated in subequal amounts (90 percent), and mudstone (10 percent). Siltstone is medium gray (N5) to light olive-gray (5Y 6/1) in beds less than 1 cm. thick. Mudstone is dark greenish-gray (5GY 6/1), weathers yellowish-gray (5Y 8/1), silty, micaceous, beds occur 2.1, 4.9, 10.2, 15.6, 16.2, 16.8, 17.3, 18.7, 20.1, and 20.4 feet above base of unit. Basal and upper contacts of unit sharp; basal 0.2 foot is olive-black (5Y 2/1) shale. . . . . 21
10. Shale and interlaminated siltstone, like unit 11 but less resistant and less carbonaceous. Silt laminae are medium gray (N5) and are typically less than 2 mm. thick, rarely in beds up to 2 cm. thick. Clay laminae are dark gray (N3) and less than 1 mm. thick. Two greenish-gray (5GY 6/1) mudstone and shale beds, 0.1 foot thick, occur at 31 and 37 feet above base. Near base, unit is shalier and pale yellowish-brown (5YR 6/2), weathers light brown (5YR 6/4). Foerstia (sampled) common to abundant in zone, 43 feet thick, beginning 13 feet above base . . . . . 57
9. Covered; offset to creek bed to northeast . . . . . 97
8. Mudstone with interbedded siltstone exposed in creek. Mudstone is olive-gray (5Y 7/1), slightly silty, in beds 0.1 to 0.2 foot thick. Siltstone is grayish-orange (10YR 7/4), with limonitic stain, planar lamination; evenly bedded with beds lensing locally . . . . . 1+
7. Shale, brownish-black (5YR 2/1), fissile, brittle, with silty laminae one or two grains thick; unidentifiable black (fish part?) debris and conodonts; limonite-stained joints and parting surface; sampled. . . . . 1.5
6. Clay mudstone, like unit 8. . . . . 0.1
5. Shale, brownish-black (5YR 2/1), like unit 7. . . . . 0.5
4. Mudstone, olive-gray (5YR 4/1) to dusky brown (5YR 2/2), slightly silty . . . . . 0.3

Devonian (continued):	Thickness (feet)
Chattanooga Shale (continued):	
3. Shale, brownish-black (5YR 2/1), like unit 7, rare, black spores; dip 40° . . . . .	11
2. Covered . . . . .	90
1. Exposure at dip slope opposite green dumpster. Shale, like unit 7, spores abundant; interbedded at base with greenish-gray mudstone. Dip 37° . . . .	10+
Total Chattanooga Shale (incomplete). . . . .	<u>761.4</u>
Total section, about. . . . .	<u>771</u>

[Note: Units 22 through 26 may be equivalent to Big Stone Gap Member as used by Hasson (1973, p. 21).]

## SECTION 10

### Mountain Branch Section

Incomplete section of Ohio Shale and Berea Sandstone exposed in drainage of Mountain Branch of Elkhorn Creek and along access road to Johnson Brothers Limestone Quarry, off Kentucky Highway 197, 4.7 miles south of junction with Kentucky Highway 80 in Elkhorn City, Pike County, Kentucky. Base of section is in gulley 1,000 feet FNL x 100 feet FWL of Sec. 24-J-86; top of section is along access road 1,950 feet FNL x 100 feet FEL Sec. 25-J-86 (Hellier quadrangle). Base of supplementary section is in fault contact with Pennsylvanian sandstone also exposed along access road 700 feet FNL x 925 feet FEL Sec. 25-J-86. Section measured, described, and sampled using Jacob's staff, tape, Abney level, and Brunton compass and its radioactivity profile measured using scintillometer by R. C. Kepferle, P. E. Potter, and Linda J. Provo, June 15-16, 1976.

Mississippian:	Thickness (feet)
Berea Sandstone (incomplete):	
29. Covered to top of interval with float blocks of Berea Sandstone exposed in ditch and on slope above ditch . . . . .	45+
28. Siltstone (90 percent) and shale (10 percent). Siltstone is medium gray (N5) to light olive gray (5Y 6/1), weathers yellowish gray (5Y 7/2) to grayish yellow (5Y 8/4); massive; load casts	

Mississippian (continued):	Thickness (feet)
Berea Sandstone (continued):	
on soles; maximum bed thickness 2.5 feet with bed thickness generally increasing upward. Interbedded shale is greenish gray (5Y 5/1), weathering to yellowish gray (5Y 6/1) . . . . .	47
27. Shale (90 percent), greenish-gray (5Y 5/1), as above; with a few siltstone interbeds (10 per- cent) containing black, carbonaceous debris, as above; siltstone beds typically 0.3 foot thick; contact with underlying Ohio Shale is sharp and conformable . . . . .	9
Total Berea Sandstone . . . . .	<u>101+</u>
Devonian:	
Ohio Shale (incomplete):	
26. Shale, brownish-black (5YR 2/1), fissile, with some dark gray (N3) siltier beds which are less fissile and weather spheroidally; orbiculoid and linguloid brachiopods sparse to common in upper 12 feet; lowermost 10 to 12 feet are covered; sampled at upper contact and 28 feet above base . . . .	39
25. Disturbed zone of contorted black shale beds. . . . .	7
24. Shale, olive-black (5Y 2/1), silty, micaceous, brittle, laminated but not fissile in lower 15 feet with fissility improving upward, blocky weathering; red-brown <u>Tasmanites</u> spores, <u>Lingula</u> sparse near base; black carbonaceous debris as sand- and silt-sized flecks, throughout, inter- bedded with thin, 0.1 foot lenticular to nodular, dark-gray (N3) to medium dark-gray (N4) siltstone beds throughout. Maximum thickness of siltstone beds is 1.0 foot at 70 feet above base (sampled). Shale sampled at base and 50 feet above base. . . . .	77
23. Siltstone and mudstone. Siltstone is light bluish- gray (5B 7/1), weathers grayish-orange (10YR 7/4), uniform, argillaceous; micaceous; abundant flecks of black carbonaceous debris; planar and cross- lamination and rare, faint current lineation on soles of beds commonly 0.1 to 0.5 foot thick; siltstone beds best developed and most abundant 5-25 feet above base of unit where it makes up	

Devonian (continued):

Thickness  
 (feet)

Ohio Shale (continued):

- 60 percent of unit; less abundant upward in unit; interbedded and intergradational with mudstone. Mudstone is light olive gray (5Y 5/2) to olive gray (5Y 3/2) to dark greenish gray (5GY 4/1), in beds 0.1 to 1.0 foot thick; slightly silty and micaceous; subconchoidal fracture, incipient shaly parting poorly developed; limonitic stain. More resistant beds of silty mudstone in beds 0.1 to 0.4 foot thick have uneven fracture, locally sharp-based, mottled due to bioturbation (?); rare, small flecks of shiny black carbonaceous matter; ovoid limonitic, clayey nodules 0.2 foot in diameter at 45 and 110 feet above base. Mudstone beds more abundant in upper 120 feet of unit and gradually become more fissile upward in section; mudstone sampled at 7 and at 142 feet above base; siltstone sampled at 10 and 143 feet above base. . . . 147
22. Shale, olive-black (5Y 2/1) to olive-gray (5Y 3/1), micaceous; silty, with numerous very thin silt laminae one or two grains thick; silty laminae are more abundant in a zone 10 to 12 feet above base of unit, intermediate in color between pale yellow brown (10YR 5/2) and brownish-gray (5YR 4/1); burrowing in silty laminae in uppermost foot of unit with a 0.1-foot-thick, light-olive-gray (5Y 6/1) siltstone bed; abundant black coaly plant remains as much as 1 cm. in length along bedding planes; few dark brown to black spores. About 18 feet above base of unit is a low angle fault which offsets bedding. Sampled black shale at 7 feet above base. Ravine enters from east just above base of this unit. . . . . 34
21. Dark shale (80 percent) and light mudstone (20 percent), interbedded in about 25 couplets. Dark shale is brownish-black (5YR 2/2), rarely medium gray (N5), in beds ranging from less than 1 foot to as much as 9 feet thick; micaceous; quartzose silt in lighter colored laminae, which may pinch and swell; abundant resinous Tasmanites spores; and rare silt-filled burrows. Mudstone is greenish gray (5GY 5/1) to medium light gray (N6), weathering to grayish yellow green (5GY 7/2), subconchoidal to flaggy fracture; fractures coated

Devonian (continued):	Thickness (feet)
<p>Ohio Shale (continued):            with hematite, dark yellowish-orange (10YR 6/6) to pale reddish-brown (10R 5/4); fine flecks of black organic matter. Boundaries between beds sharp. Couplets are thinnest in a zone 5 feet thick beginning 23 feet above base of unit. Unit is more resistant and hackly in appearance on slope than is underlying unit 20. Sampled greenish-gray mudstone 15 feet above base and brownish-black shale 15.5 feet above base . . . . .</p>	63
<p>20. Mudstone (70 percent) and siltstone to very fine-grained sandstone (30 percent). Mudstone is light gray (N7), micaceous, contains very fine black shreds of organic matter; contact gradational with overlying brownish-black shale; thin, carbonaceous shale near middle of unit. Siltstone is light olive gray (5Y 6/1), laminated, in discrete beds less than 0.1 foot thick in lowest 5 feet of unit and becoming less well defined upward in the unit. Sampled siltstone 7 feet above base and mudstone at 6.5 feet above base. . . .</p>	20
<p>19. Covered interval. . . . .</p>	7
<p>18. Shale, dusky brown (5YR 2/2) to dusky yellowish brown (10YR 2/2), weathers dark yellowish brown (10YR 4/2) to grayish brown (5YR 3/2), silty, laminated, micaceous; sampled 3 feet above base . . .</p>	5
<p>17. Covered interval. . . . .</p>	18
<p>16. Mudstone (60 percent) and siltstone (40 percent). Mudstone is greenish gray (5GY 5/1), weathers light greenish gray (5GY 7/1). Siltstone and silty shale are light olive-gray (5Y 6/1), weather moderate yellowish brown (10YR 5/4), planar lamination, in beds 2-4 cm. thick. Eight feet above base is a 1-foot thick limonite-cemented zone which may be related to a fault along bedding plane; sampled limonitic zone 8 feet above base and mudstone 10 feet above base . . .</p>	18
<p>15. Covered interval. . . . .</p>	12

Devonian (continued):

Thickness  
 (feet)

Ohio Shale (continued):

14. Mudstone, greenish-gray (5GY 5/1, like unit 16; and siltstone, light olive-gray (5Y 6/1), like unit 16; sampled mudstone 2 feet above base of unit and siltstone 3 feet above base of unit. . . . . 25
13. Covered by recent (?) slide material. . . . . 125
12. Mudstone (80-90 percent), greenish-gray (5GY 5/1), and thin siltstone (10-20 percent), light olive-gray (5Y 6/1), poorly indurated, massive bedding; sampled siltstone 21 feet above base and mudstone at 21.5 feet above base . . . . . 40
11. Covered interval, may be mudstone. Underlying units are measured and described from unnamed gulley. . . . . 84
10. Mudstone (80 percent), greenish-gray (5GY 6/1) and thin interbeds of dark shale (20 percent); sampled mudstone at top of unit . . . . . 6
9. Mudstone, olive-gray (5Y 4/1) to greenish-gray (5GY 5/1) interbedded with equal amounts of shale, black (N1) to olive-black (5Y 2/1); fissile, brittle, fractured, micaceous, carbonaceous, Tasmanites spores; sampled dark shale 3 feet above base . . . . . 7
8. Shale (80 percent), black (N1); with three interbedded greenish-gray shale beds ranging in thickness from less than 0.1 foot to 0.4 foot and separated by at least 1 foot of black shale; sampled 7 feet above base . . . . . 13
7. Shale and mudstone in equal amounts; shale like unit 4 and mudstone like unit 5; beds 0.1 to 0.3 foot thick in 5 or 6 couplets; numerous minor fractures crosscut unit obliquely with offset up to 0.1 foot; sampled. . . . . 5
6. Mudstone (70 percent), like unit 5, interbedded with black shale beds like unit 4 less than 0.1 foot in thickness; mudstone beds 0.3 to 0.8 foot thick; sampled 4 feet above base. . . . . 12

Devonian (continued):

Thickness  
 (feet)

Ohio Shale (continued):

5. Mudstone, olive-gray (5Y 4/1) to greenish-gray (5GY 5/1), brittle; partly covered; sampled 3 feet above base . . . . .	15
4. Shale, black (N1) to olive-black (5Y 2/1), fissile, brittle, fractured, carbonaceous; micaceous, <u>Tasmanites</u> spores; sampled 5 and 15 feet above base . . . . .	22
3. Covered interval. . . . .	25
2. Shale, grayish-black (N2), highly fractured, carbonaceous; top of unit covered; sampled. . . . .	5
1. Covered interval, to stream gulley below. . . . .	<u>20</u>
Total Ohio Shale (incomplete) . . . . .	<u>851+</u>
Total section measured. . . . .	<u>952</u>

APPENDIX 2. --SAMPLE NUMBER, URANIUM CONTENT, AND LOCATION OF OUTCROP  
 AND CORE SAMPLES ANALYZED FOR URANIUM OXIDE.

SAMPLE NUMBER	U <sub>3</sub> O <sub>8</sub> (ppm)	LOCATION
17317	74	Roadcut in Chattanooga Shale on Kentucky Highway 90, 2 mi east of bridge over Cumberland River at Burkesville, Cumberland, County, Kentucky; 0.1 m above basal contact.
17318	47	Same location; at upper contact of Chattanooga Shale.
17319	36	Outcrop of Chattanooga Shale in Pulaski County Park, on Kentucky Highway 1248, 1.3 mi north of its junction with Kentucky 80 (7.2 mi west-southwest of West Somerset, Pulaski County, Kentucky).
17320	19	Outcrop of Chattanooga Shale at dead end of Ringgold Road, 4.2 mi from its junction with Cumberland Parkway at Somerset, Pulaski County, Kentucky; 1.75 m below upper contact.
17321	36	Roadcut in New Albany Shale on west side of U. S. Highway 127, about 1.3 mi northeast of Liberty, Casey County, Kentucky.
17322	26	Outcrop in New Albany Shale on dirt land, just before descent to Dix River Valley, 0.5 mi north of U. S. Highway 150 about 0.75 mi east of Crab Orchard, Lincoln County, Kentucky.
17323	37	Outcrop of New Albany Shale in bed of Mason Fork of Flint Lick Creek, on unnamed secondary road off Kentucky Highway 954, 3 mi southwest of Berea, Garrard County, Kentucky.
17324	11	Outcrop of New Albany Shale on west side of Dogwood Drive, north of Kentucky Highway 21 about 0.6 mi west of Berea, Madison County, Kentucky; 0.9 m above basal contact.
17325	20	Roadcut in New Albany Shale on north side of unnamed road 0.9 mi east of its junction with U. S. Highway 421, about 0.1 mi south of junction of U. S. 421 and Kentucky 21, Big Hill, Madison County, Kentucky.

SAMPLE NUMBER	U <sub>3</sub> O <sub>8</sub> (ppm)	LOCATION
17326	29	Roadcut in New Albany Shale 0.1 mi east of Madison-Estill County line, on Kentucky Highway 594, 7.8 mi east of its junction with U. S. 421, northeast of Big Hill, Estill County, Kentucky.
17327	27	Roadcut in New Albany Shale on north side of Kentucky Highway 499, 1.8 mi west of Dug Hill, Estill County, Kentucky.
17328	33	Railroad cut in New Albany Shale on north side of Kentucky Highway 1571, 0.4 mi beyond its junction with Kentucky 52 at Revenna, Estill County, Kentucky (north of Kentucky River).
17329	19	Roadcut in Ohio Shale on Kentucky Highway 10, 1.1 mi west of junction of Kentucky 8 and 10 at Vanceburg, Lewis County, Kentucky; 1 m above base of measured section.
17330	28	Same location; 2.2 m above base of measured section.
17331	29	Outcrop of Ohio Shale in stream bed on gravel road up Rock Camp Run, 1.1 mi north of Kentucky Highway 344, 0.3 mi east of Petersville, Lewis County, Kentucky.
17332	17	Roadcut in Ohio Shale 0.4 mi north on the east side of Spring Road, 0.7 mi east of Wallingford, Fleming County, Kentucky.
17333	62	Roadcut in Sunbury Shale, Bedford Shale, and Borden Formation on north side of Interstate 64, 4.3 mi west of Morehead (Kentucky Highway 32) interchange, Rowan County, Kentucky; sampled Sunbury Shale 0.6 m below upper contact.
17334	27	Same location; sampled Sunbury Shale 2 m below upper contact.
17335	25	Roadcut in Ohio Shale on south side of Interstate 64, 6.0 mi west of interchange at Morehead, Rowan County, Kentucky; at base of Ohio Shale.
17336	28	Roadcut in New Albany Shale on north side of Mountain Parkway just west of Clay City interchange (Exit 16), Powell County, Kentucky; 2.1 m above basal contact.

SAMPLE NUMBER	U <sub>3</sub> O <sub>8</sub> (ppm)	LOCATION
17337	31	Same location; 7.6 m above basal contact.
17338	42	Same location; 9.6 m above basal contact.
17339	47	Same location; 10 m above basal contact.
17340	35	Same location; 18 m above basal contact.
17341	36	Same location; 23 m above basal contact.
17342	19	Roadcut in New Albany Shale on east side of Kentucky Highway 1057 at Stanton (Kentucky 213) interchange of Mountain Parkway, Powell County, Kentucky; 9.1 m below upper contact.
17343	6	Brazil core.
17344	44	Brazil core.
17345	32	New cut in New Albany Shale at building site on west side of Kentucky Highway 11, about 1 mi north of junction Kentucky 11 and 15 at Clay City, Powell County, Kentucky.
17346	81	Roadcut in Chattanooga Shale on east side of Interstate 65, 1 mi south of junction I-65 and U. S. 64 at Pulaski, Giles County, Tennessee; .88 m above basal contact.
17347	77	Roadcut in Chattanooga Shale on east side of Tennessee Highway 7, 1.8 mi southeast of Snow Creek, near Santa Fe, Maury County, Tennessee.
17348	79	Roadcut in Chattanooga Shale on U. S. Highway 64, 2.4 mi east of city limits of Kelso, Lincoln County, Tennessee; .4 m above basal contact.
17349	106	Roadcut in Chattanooga Shale on east side of U. S. Highway 231, 10.7 mi north of Fayetteville, Lincoln County, Tennessee; 0.5 m below upper contact.
17350	58	Roadcut in Chattanooga Shale on both sides of U. S. Highway 41, 1.1 mi northwest of Noah Fork Bridge, near Noah, Coffee County, Tennessee; 0.67 m above basal contact.

SAMPLE NUMBER	U <sub>3</sub> O <sub>8</sub> (ppm)	LOCATION
17351	50	Same location; 2 m below upper contact.
17352	49	Roadcut in Chattanooga Shale on east side of Tennessee Highway 53, 6.2 mi south of Dekalb-Cannon County line, Cannon County, Tennessee; 0.72 m above basal contact.
17353	23	Same location; 2 m below upper contact.
17354	23	Roadcut in Chattanooga Shale and Maury Shale on north side of U. S. Highway 70, 3.2 mi west of Smithville, Dekalb County, Tennessee; 0.47 m below Dowelltown-Gassaway contact.
17355	43	Same location; 1.75 m below upper contact of Gassaway member.
17356	33	Same location; in Maury Shale, 0.1 m below upper contact.
17357	95	Highway cut in Chattanooga Shale and Maury Shale at east end of Sligo Bridge over Center Hill Reservoir, U. S. Highway 70, east of Smithville, Dekalb County, Tennessee; in Maury Shale, 0.15 m below upper contact.
17358	95	Same location; in Maury Shale, 0.4 m below upper contact.
17359	72	Same location; in Chattanooga Shale at basal contact of Gassaway member.
17360	49	Same location; in Chattanooga Shale, 0.3 m above basal contact of Dowelltown member.
17361	66	Highway cut in Chattanooga Shale on Tennessee Highway 53, 0.7 mi north of entrance to Dale Hollow Dam overlook (west side), north east of Celina, Clay County, Tennessee; 0.1 m above basal contact.
17362	51	Roadcut in Chattanooga Shale near north end of Dale Hollow Dam, opposite overlook, near Celina, Clay County, Tennessee; 3.1 m above basal contact.
17363	34	Same location; 1.75 m below upper contact.

SAMPLE NUMBER	U <sub>3</sub> O <sub>8</sub> (ppm)	LOCATION
17364	64	Highway cut in Chattanooga Shale 0.4 mi west of west end of bridge over Obey River, on Tennessee Highway 53, near Celina, Clay County, Tennessee; 0.5 m above basal contact.
17365	40	New roadcut in Chattanooga Shale on west side of Tennessee Highway 53 just beyond Dry Fork, south of Celina, Clay County, Tennessee; 0.84 m below upper contact.
17366	82	Same location; 3.5 m below upper contact.
17367	23	Same location; 0.2 m above basal contact.
17368	14	Roadcut in Chattanooga Shale on Tennessee Highway 135, 8.7 mi east of the junction of Tennessee 135 and 53 at Gainesboro, Jackson County, Tennessee; at basal contact.
17369	34	Same location; 1.0 m below upper contact.
17370	83	Outcrop of Chattanooga Shale in bed of Flint River, along Upcreek Road near Sulphur Springs, Madison County, Alabama.
17371	95	Roadcut in Chattanooga Shale on Buddy Williamson Road about 0.35 mi east of its intersection with Mint Springs Road, 2.8 mi west of Plevna, Madison County, Alabama.
17372	69	Outcrop of Chattanooga Shale 0.1 mi. east of bridge over unnamed creek on Carriger Road, 1 mi east of Fisk, Madison County, Alabama.
17373	40	Roadcut in Chattanooga Shale on Tennessee Highway 56 at south approach to Hurricane Bridge over Center Hill Reservoir, 1.6 mi south of the bridge and about 0.7 mi north-northeast of Smithville, Dekalb County, Tennessee; at upper contact.
17374	59	Same location; 4.5 m below upper contact.
17375	32	Same location; 0.5 m below Dowelltown-Cassaway member contact.

SAMPLE NUMBER	U <sub>3</sub> O <sub>8</sub> (ppm)	LOCATION
17377	30	Core of Ohio Shale: Lew Bates, Jr. No. 2 Kocheiser Sec. 30, Washington Twp., 422 ft FSL x 550 ft FEL Richland County, Ohio 60.5 ft below top.
17378	34	Same location; 78.5 ft below top.
17379	24	Same location; 416 ft below top.
17380	7	Same location; 433 ft below top.
17381	20	Core of Ohio Shale: Kentucky-West Virginia Gas No. 7239 Combs 1690' FNL x 325' FWL of Sec. 19-K-76 Perry County, Kentucky 8.6 ft below top.
17382	25	Same location; 41.5 ft below top.
17383	6	Same location; 77.2 ft below top.
17384	6	Same location; 175 ft below top.
17385	30	Same location; 240.4 ft below top.
17386	38	Same location; 292.6 ft below top.
17387	13	Same location; 302 ft below top.
17388	10	Same location; 319.8 ft below top.
17389	4	Same location; 333 ft below top.
17390	38	Same location; 229.7 ft below top.
19893	22	Nearly complete section of Ohio Shale, Bedford Shale, Berea Sandstone and Sunbury Shale exposed for 5.1 miles in roadcuts along both sides of Ohio Highway 32 near Peebles, Franklin Township, Ohio (Adams County); sampled Ohio Shale 210 feet below upper contact.
19894	35	Same location; 200 feet below upper contact.

SAMPLE NUMBER	$U_3O_8$ (ppm)	LOCATION
19895	26	Same location; 174 ft below upper contact.
19896	27	Same location; 132 ft below upper contact.
19897	8	Same location; 76 ft below upper contact.
19898	6	Same location; 62 ft below upper contact.
19899	20	Same location; 61 ft below upper contact.
19900	28	Same location; 33 ft below upper contact.
19901	48	Same location; 18 ft below upper contact.
19902	19	Same location; at upper contact.
19903	28	Same location; 77.6 ft below upper contact.
19904	23	Same location; 70.9 ft below upper contact.
19905	33	(Duplicate of 19899.)
19906	15	Incomplete section of Ohio Shale and Berea Sandstone exposed in drainage of Mountain Branch of Elkhorn Creek and along access road to Johnson Brothers Limestone Quarry, off Kentucky Highway 197, 4.7 mi south of its junction with Kentucky Highway 80 in Elkhorn City, Pike County, Kentucky. Base of section is in gulley 1,000 ft FNL x 100 ft FWL of Sec. 24-J-86; top of section is along access road 1,950 ft FNL x 100 ft FEL of Sec. 25-J-86 (Hellier quadrangle); sampled Ohio Shale 796 ft below upper contact.
19907	6	Same location; 760 ft below upper contact.
19908	8	Same location; 752 ft below upper contact.
19909	7	Same location; 731 ft below upper contact.
19910	6	Same location; 385 ft below upper contact.
19911	4	Same location; 352 ft below upper contact.
19912	8	Same location; 276 ft below upper contact.

SAMPLE NUMBER	U <sub>3</sub> O <sub>8</sub> (ppm)	LOCATION
19913	18	Same location; 56 ft below upper contact.
19914	3	Same location; 11 ft below upper contact.
19915	1	Same location; at upper contact.
19916	10	Same location; 786 ft below upper contact.
19917	10	Same location; 751 ft below upper contact.
19918	4	Same location; 384.5 ft below upper contact.
19919	9	Same location; 351.5 ft below upper contact.
19920	7	Same location; 53 ft below upper contact.
19921	8	Incomplete section of Chattanooga Shale and Grainger Formation exposed for 0.55 mi in roadcuts and creekbeds along northeastern side of Tennessee Highway 31 (Flat Gap Road); top of Chattanooga Shale is located 4.25 mi north of junction of U. S. Route 11W and Tennessee Highway 31 at Mooresburg, Hawkins County, Tennessee (Lee Valley quadrangle); sampled Chattanooga Shale 131 ft below upper contact.
19922	18	Same location; 649 ft below upper contact.